METAL
PROGRESS

SC CONTROLLED ATMOSPHERE MALLEABLEIZING

Photomicrograph at 100X showing typical structure of iron malleableized in SC Atmosphere Furnace.
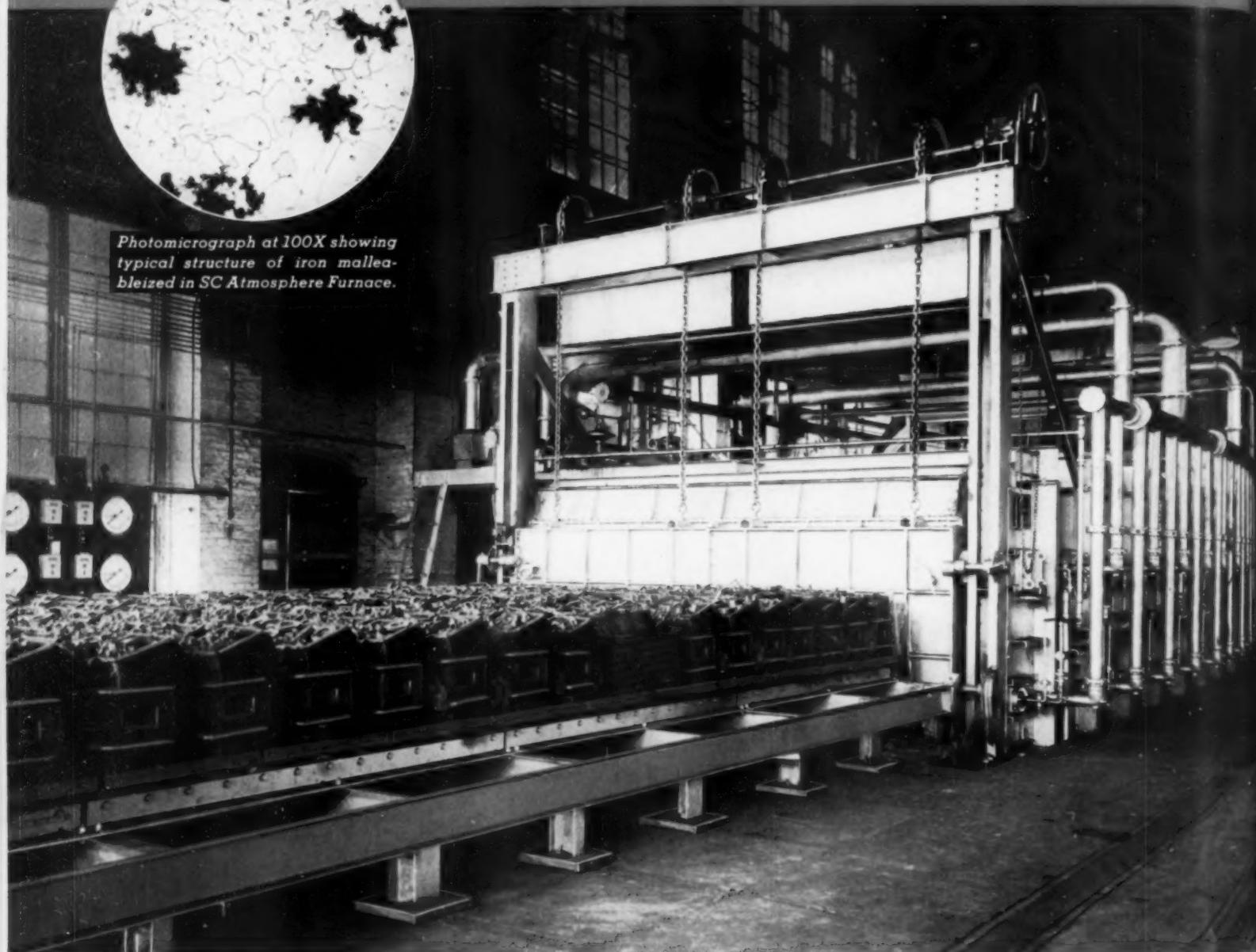
● Marked reductions in the annealing cycle have been made in malleableizing furnaces equipped with SC gas-fired *radiant tube* heating elements and provided with a controlled atmosphere. Where previously but 25% of the total load heated was castings, in these new continuous and batch-type controlled atmosphere furnaces 75% of the total load is net. In protecting against scaling and excessive decarburization by use of controlled atmosphere, it was possible to eliminate the tare weight of pots and boxes, compound, and cars—

thus saving fuel and time as well as considerable labor. The malleableized iron produced in this type of furnace is a fully annealed standard commercial iron essentially free of pearlite. See photomicrograph at 100 magnifications. During graphitizing and cooling periods particularly the gas-fired SC *radiant tube* heating elements are very

efficient in permitting exact control of furnace conditions. Controlled atmosphere malleableizing is the right answer to lower costs and higher production. Ask a Surface Combustion engineer in to talk it over with you if you make or use malleable iron. Without obligation, write for information, to

SURFACE COMBUSTION CORPORATION, Toledo, Ohio

SURFACE SC COMBUSTION

Builders of ATMOSPHERE FURNACES and HARDENING, DRAWING, NORMALIZING, ANNEALING FURNACES for CONTINUOUS or BATCH OPERATIONS

Metal Progress

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Cover for this month is from a poster by E. E. Maurus, a French artist whose huge stylized designs (using generous amounts of metals) covered the facade of the building devoted to Food and Drink at the Paris International Exposition

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AMERICAN SOCIETY for METALS

By Klaus L. Hansen
Consulting Engineer
Harnischfeger Corp.
Milwaukee, Wisconsin

Digest of welding

processes and

equipment

I N THIS ARTICLE it will be the aim to characterize the principal welding processes and then to devote a little extra space to the most widespread process of all — arc welding — paying particular attention to certain important characteristics of the special electrical machinery utilized.

Welding has been briefly defined as "a localized consolidation of metals by means of heat." The welding process is broadly divided into two main divisions: *(a)* Plastic welding and *(b)* fluid or fusion welding. These two designations are, of course, derived from the state of the portions of the surfaces to be united at the time of welding. In plastic welding the temperatures are not sufficiently high to liquefy the metal, and a blow or pressure is an essential requirement to complete the joint.

Plastic welding is divided, according to the source of heat employed, into two classes — forge welding with furnace or fire heat, and electric resistance welding.

Forge welding is by far the oldest process of joining metals. As contrasted with all other processes, which are developments of the last 50 years, forge welding dates back to antiquity. Long a faithful servant of mankind, it has in recent years largely given way to the modern forms of welding, despite the development of modern machinery for performing the o p e r a t i o n — as, for instance, the making of long seams in heavy-walled pressure vessels.

Electric Resistance Welding — As the name implies, the heat required to bring the metal to the plastic state is obtained by passing a high current through the resistance existing at the contact of the edges or surfaces where union is to take place. As is well known, the heat liberated at the junction point is proportional to the square of the current multiplied by the resistance at the contact. When the heat is sufficiently advanced, pressure is applied by suitable mechanical means. The pressures vary over a wide range according to the type of materials to be joined, and may reach as high as 50,000 to 60,000 psi.

The necessary requirement for successful resistance welding is correct coordination of current, time, and pressure. The electrical circuit is essentially one of low voltage and high current. Because of the ease of transformation, alternating current is almost always employed, and the immediate source of current is a transformer built into the machine with a secondary consisting usually of one turn only. The primary is provided with taps so that the ratio of transformation, and thereby the secondary output, can be varied over a certain range.

The one-turn secondary circuit also includes the leads to the welding machine, the clamps or electrodes, and the sections of the pieces to be welded adjacent to the point of contact, as well as the contact itself. A circuit consisting of such varied elements and carrying heavy currents has given rise to many special problems. For instance, copper conductors must be properly laminated to keep down losses from eddy currents, and water cooling of the electrodes is frequently resorted to. The con-

figuration and area of the secondary loop are factors in determining the secondary reactance, which in turn is an important limitation of the transformer's output.

Resistance welding, in turn, is subdivided into butt welding (which includes flash welding and electro-percussive welding), spot welding and seam welding.

Butt Welding — In this process pieces of the same cross-section are mechanically gripped and then pressed together while a large current is passed through the area of contact. The voltage drop at the abutting ends when the pieces are pressed together is usually on the order of one or two volts, and the current required to produce the necessary heat is, therefore, very high. If this voltage drop can be raised by any means, the current can be correspondingly reduced. One way of accomplishing this is to establish a momentary arc before applying the pressure, and this variation is known as

Flash Welding — When the edges to be welded are brought together slowly, with voltage applied, arcing takes place as the first points come in contact. This violent arcing volatilizes metal and increases the distance between the edges at this point, with the result that the arc moves rapidly to other points of lower resistance. Thus the arc flits from point to point, increasing in violence with increasing speed of approach, until uniform flashing occurs over the entire area when pressure completes the weld.

Electro-Percussive Welding is a form of flash welding, not extensively used, in which a momentary arc is established by discharging a definite amount of stored energy and the welding operation completed by a percussive blow delivered simultaneously. The energy may be stored electrostatically in a condenser, or electromagnetically in the core of a transformer. The percussive blow is usually secured by means of a falling weight. This process has been used principally for butt welding wires, and with considerable success in joining dissimilar metals.

Spot welding is accomplished by placing overlapping sheets between two blunt electrodes and passing a very large current from electrode to electrode through the sheets. When the adjacent metal surfaces are heated to plasticity, pressure is applied and the sheets are welded togeher in a spot approximately equal in size to the end of the electrode.

Success has to a large extent depended on the development of suitable electrode materials. The exacting demands require high electrical and heat conductivity, fairly high yield point at elevated temperatures, a considerable degree of hardness, and ability to withstand fairly high temperatures. Some very fine work in powder metallurgy of copper and tungsten has resulted in developing the present-day electrode materials.

Seam Welding — Sheets can be welded together in a continuous seam by passing them between wheel-like electrodes which transmit the current and the mechanical pressure required. This method is applicable only to

Oscillogram of Welding Arc Showing Frequent but Momentary Short Circuits Caused by Droplets of Molten Metal. Marks at bottom represent time intervals of 1/60 sec.
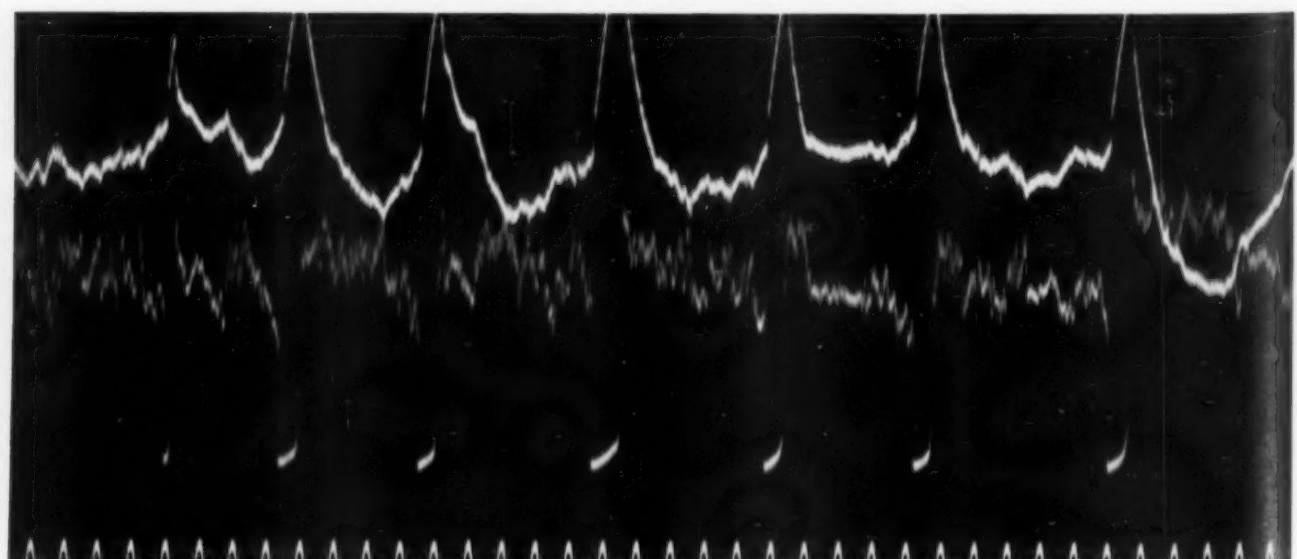
clean metal; any slight amount of mill scale or other surface impurities will result in "burns" or failure to weld. Furthermore, the disks soon become pitted and oxidized. To overcome these difficulties a modified form has been developed that is called

Stitch welding, intermediate between seam welding and spot welding. The sheets to be welded are passed between rolls, the same as in seam welding, but the current is interrupted periodically at very brief intervals so that the welds form a series of overlapping spots. Up to certain currents and speeds mechanical devices may be used for making and breaking the current, but for large currents and extremely high speeds electronic devices are resorted to. Electron tubes are also useful for controls which interrupt and re-establish the current according to a definite program for each single spot, as may be necessary for heavier steel plate, or for non-ferrous sheets.

Fusion Welding — In fusion welding the metals to be joined are in the fluid state at the time of welding and heat alone is the agency used to make the weld. Fusion welding is divided according to the source of heat into three groups, gas welding, electric arc welding, and thermit welding. Strictly speaking, various types of soldering, brazing and copper-brazing in controlled atmospheres should be included, for the jointing metal doubtless forms a liquid alloy with the metal being joined at the contacting surfaces.

Gas Welding — The high temperature flame used in gas welding is produced by combustion of acetylene in oxygen. When these gases are mixed in a certain proportion the flame is known as "neutral;" with excess of oxygen it is called "oxidizing," and with an excess of acetylene, "carburizing." Each has its proper use. Today the gas flame is used to a much greater extent for cutting steel, and of course a predominantly oxidizing flame is then used, for the metal removed in cutting is literally burned — the very opposite effect from that desired when welding.

The oxy-acetylene flame is extensively used in brazing operations when joining steel and cast iron, especially where the filler material is a copper alloy high in zinc, such as tobin bronze. It is also widely used in welding non-ferrous metals, particularly aluminum and its alloys. Another field where it is still holding its own is in welding of light gage steel sheet and alloy steel. An example of the latter is airplane tubing. Much welding on overland pipe lines is also done, frequently using multi-flame heads or special technique and welding rods with carburizing flame.

Atomic Hydrogen Welding is a combination of arc and gas welding. The atomic hydrogen torch contains two tungsten wires with ends a fraction of an inch apart. A jet of hydrogen is projected between these points, across which arcs a current at comparatively high voltage (that is, 440 volts). The intense heat causes the hydrogen molecules to be split up into their constituent atoms, and the recombination a little distance below liberates the energy previously used in dissociating the mole-

A Certain Welding Generator, Set for 200 Amperes at 40 Volts Load, Is Short Circuited and Then Suddenly Thrown on Load at T. Note transient voltage peak and then gradual climb toward "static" conditions
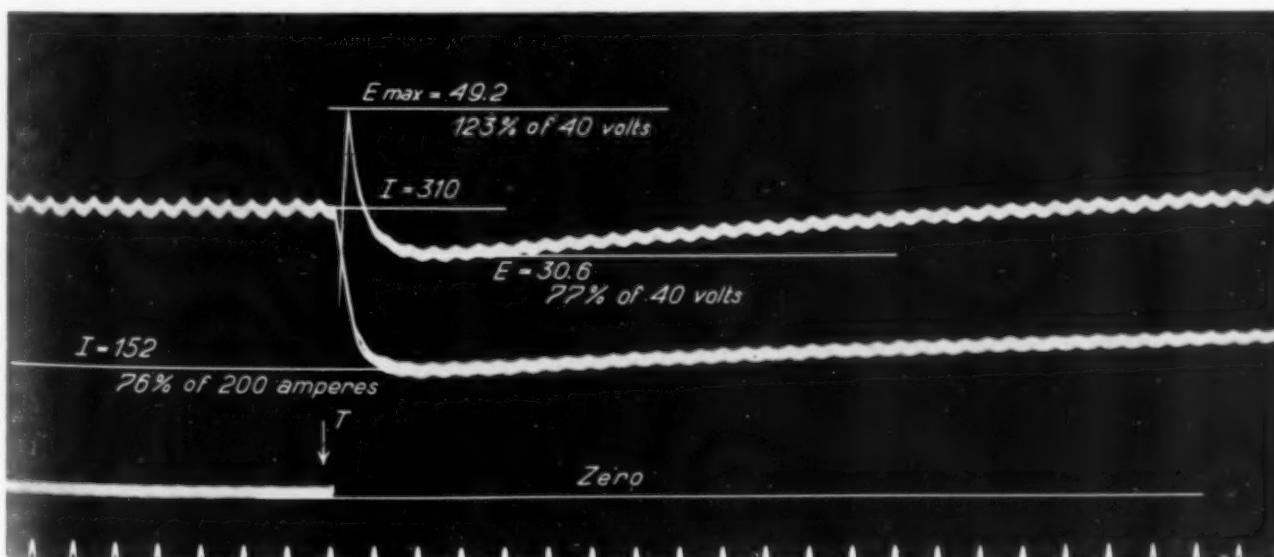
cules. A flame at very high temperature is so produced. Furthermore, the hydrogen provides an atmosphere which protects the molten metal from the atmospheric gases, and sound welds are the result.

Thermit Welding — The strong affinity of metallic aluminum for oxygen is utilized to great advantage in this interesting process.
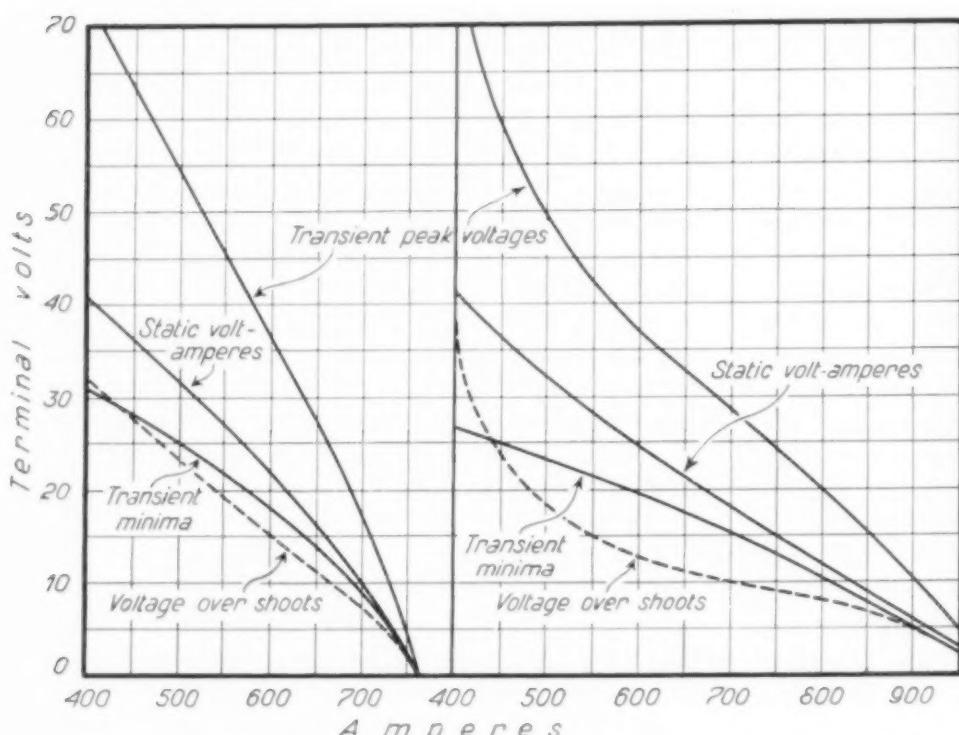
Transient and Static (Steady State) Characteristics of Two 400-Ampere Welding Generators. Opposite is microstructure of weld metal produced by each

When a mixture of iron oxide and finely powdered aluminum is ignited at one spot a chemical reaction progresses rapidly throughout the mass and a great amount of heat is liberated. The immediate result is superheated molten iron with aluminum oxide floating on the top as slag. In practice, the parts to be welded are separated slightly, a mold of such shape as to give the desired contour to the reinforcement is placed around them, and the interior cavity strongly heated by gas or oil flame. The thermit mixture is placed in a crucible above the mold and ignited. Within a few seconds, after completion of the reaction, the molten iron is tapped into the mold where it flows around and between the parts to be united, thoroughly fusing their preheated surfaces and on cooling joining them into a homogeneous mass. Thermit welding is most frequently observed by non-technical citizens when they watch maintenance crews joining

together ends of rail sections in street car lines.

Electric Arc Welding — Of all the welding processes developed within the last 50 years, are welding now has the widest field of application. In fact, the term "electric welding" without a qualifying suffix is often used as a synonym for arc welding. Arc welding is divided into two classes — carbon arc and metallic arc welding — but the carbon arc is now ordinarily confined to certain machine operations or to manual welding of copper alloys.

Metallic arc welding, in turn, may be subdivided as to the means taken to shield the hot metal from oxidation at the arc and along the finished bead — that is, whether the electrodes are bare or coated, or whether the shielding is done by substances derived from the coating, from an auxiliary gas stream or from pastes or powders previously placed along the seam.

Because of the industrial importance of metallic arc welding, and because the phenomena involved are exceedingly interesting and yet little understood, some of the requirements of arc welding will be discussed in connection with the generating equipment.

As is well known, the weld rod in metallic arc welding serves a double function — it constitutes one electrode and also furnishes the filler material as it continually melts off and flows into the weld deposit. The piece to be welded constitutes the other electrode, and the average arc gap is from $\frac{1}{8}$ to $\frac{3}{16}$ in.

The function of the arc struck between the end of the weld rod and the work is to convert electrical energy into heat energy, and the rate at which this transformation takes place is measured by the product of the current in amperes and the voltage drop across the arc. The arc consists principally of metallic vapors, and its resistance characteristics are entirely different from those of solid metallic conductors. In a solid conductor the voltage drop over any part of the circuit is proportional to the

current passing. On the other hand, the voltage across the arc is, for same arc length, approximately constant over a wide range of current. In the ordinary welding circuit the resistance of the arc *decreases* with increasing current, and vice versa. This so-called "negative resistance" of the arc is responsible for its inherent instability when the current is drawn from a source of constant voltage.

Welding generators must be designed to cope with this peculiarity. Ordinarily, in rating a welding generator the volt-ampere curve is obtained by taking readings of voltage and current when the external load is varied in suitable resistances from infinite value on open circuit to zero value on short circuit. Sufficient time is given before each reading to allow the current and voltage to settle to steady values. The readings thus obtained, plotted with current as abscissas and volts as ordinates, are known as the static or steady state volt-ampere curve of the generator. This curve must be inclined downward toward the right if the generator is to overcome the inherent instability of the arc.

But in metallic arc welding more severe conditions than the inherent instability of the arc have to be met and overcome. The figure on page 116 shows an oscillogram of the arc voltage and current which may be considered typical, the generator and the covered electrode used both being standard commercial articles. An automatic head was employed to feed the electrode. The voltage, as shown by the lighter, intermediate zig-zags, drops to nearly zero as drops of molten metal short-circuit the arc. Whenever this occurs, a sharp rise in current can be observed (top zig-zag line). However, at other times the current and especially the voltage fluctuate continually and never reach steady values. Unlike the steady resistance load used when taking the static volt-ampere curve, the resistance of an actual welding arc varies constantly.

When the metal is transferred across the arc in the form of fine pellets instead of drops, the periodic reduction in the arc voltage may not be so pronounced. But even then there is a noticeable variation in the arc resistance, as the stream of pellets apparently comes in gushes.

The behavior of the welding generator during the period of readjustment after a sudden change of resistance is called its transient performance, and it is, of course, an all-important feature. The oscillograph, which can trace sudden variations in current and voltage, has been used to advantage in analyzing this transient performance. For example, the second oscillogram (page 117) shows changes in current and voltage from a 200-ampere welder in suddenly going from short circuit to a load resistance corresponding to 40 volts at the place marked *T*. It will be observed that the current drops suddenly from 310 amperes, the short circuit current condition, to 152 amperes and then much more gradually climbs back to normal current of 200 amperes. The voltage rises suddenly to a sharp peak at nearly 50 volts, then

All Weld Metal Specimens, Made With Two Machines Shown on Page 118
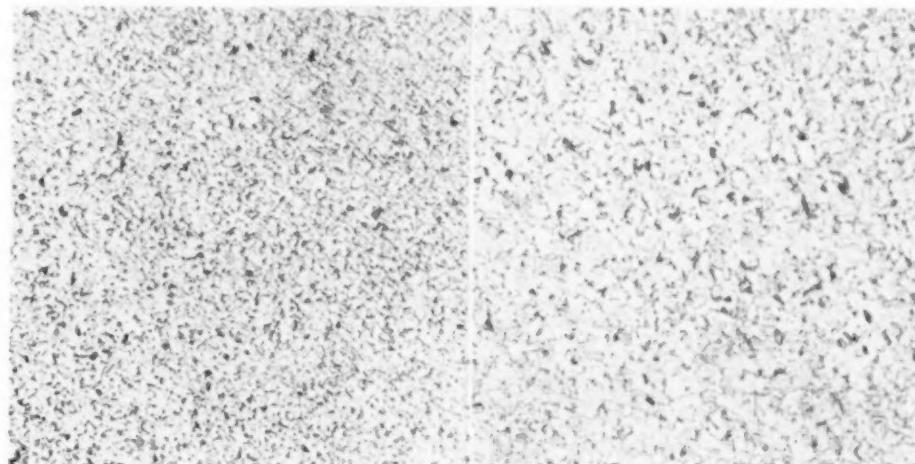
61,500	Tensile strength, psi.	61,000
43,750	Yield point, psi.	44,500
25.5	Elongation in 2 in., %	20.0
46.3	Reduction of area, %	34.1
6.58	Rate of deposition, lb. per hr.	6.29
3.53	Spatter loss, %	4.76
39.9	Charpy impact, ft-lb.	31.1

drops rather quickly to about 31, and gradually returns to normal of 40 volts.

When a droplet of metal bridges the arc gap the arc is momentarily extinguished and must be re-established quickly — indeed, it must be re-established against a higher resistance than existed in the arc immediately

preceding the short circuit. The marked overshoot of voltage shown in the second oscillogram is here of great assistance. The minimum to which the voltage drops immediately following the peak should also be high enough to maintain the arc, once it has been established. The maximum and minimum voltage fluctuations when a short circuit of the generator is opened on a predetermined resistance are, therefore, very important factors in its transient performance.

When tests like these are made for different values of external resistance, transient or dynamic volt-ampere curves similar to the static volt-ampere curve can be plotted and are very useful in predicting the welding performance of the machine. These curves are of interest principally over the range encountered in welding — from 40 volts to short circuit.

The curve sheet on page 118 shows such curves for two 400-ampere welders. Lines marked "transient peak voltages" and "transient minima" are derived from oscillograms showing changes from short circuit to resistance loads. Vertical ordinates of line marked "voltage overshoots" are the differences between ordinates of curves "transient peak voltages" and "static volt-amperes." In either case the dotted curve represents the voltage overshoots.

It will be observed that in the generator represented by the curves at left all the curves have an appreciable degree of steepness, which is very desirable. If curves marked "transient peak voltages" and "static volt-amperes" are both very steep, the tendency is that the dotted curve representing their difference is rather flat, which indicates an arc of inferior stability. In the curves at the right the static and transient volt-ampere curves are much flatter.

These matters have an influence on welding speed and properties of weld metal, as is shown by tests using a high grade electrode and automatic head — conditions other than type of generator remaining constant. The physical characteristics and the grain structure of all-weld deposits are shown in the views on page 119. Results obtained with the second machine are distinctly inferior to those obtained with the first, especially as to fineness of grain structure, spatter loss and impact value.

Many ingenious schemes have been proposed to enhance the important transient or dynamic performance of welding generators. Some of these are in practical use, others are not, but space does not permit their discussion.

Metals in Marine Engines

By Sterry B. Freeman

MOST PAPERS on modern marine engineering have a general air of optimism, so it might be timely to suggest that there still remain quite a number of points where we must confess to a certain degree of frustration. There is, of course, a theoretical limit of efficiency which Nature has imposed; it is not suggested that any complaint is leveled against Nature. The eternal striving for this efficiency is always right and to the good — it is the *cost* of achieving it that is the important qualification.

As far as the marine power plant is concerned, *turbines* are most economical in space and weight. Unfortunately, for their best performance high temperature, high pressure steam is a necessity. The metallurgist has not yet given us the metals that will unfailingly resist these temperatures and pressures.

When the turbine was first introduced many of us thought that as there was no contact between rotor and stator there would be, apart from some small wear in the bearings, no repairs and no maintenance charges to face. As it actually has turned out, the bearing wear has probably been the least troublesome item. It was not anticipated that casings would distort, crack, and erode, that shafts would bend, disks become loose, axial and radial packings leak, that blades would break, erode, and pit, and that binding wire would fail. But all these have occurred.

To prevent these happenings there has been a flood of ingenious inventions, and the materials and the processes they go through have been much improved — at greatly enhanced cost. In spite of all precautions, however, there are cases where the engineer is baffled, as when, for example, a certain row of blades will fail repeatedly although renewed in modified and improved material. The erosion of turbine casings at the later stages can, by alteration of the pressure in the stages, be transferred from one stage to another as the mischief goes on, but no means of completely preventing this damage has yet been discovered. Another common failure is that of the later stages of low pressure blading, where probably

How aluminum chairs

are made

A Photographic Story
Found at the
General Fireproofing Co.
Youngstown, Ohio
by Van Fisher

Captions by R. T. Griebling

SYMBOLIC of aluminum furniture manufacture are the welding torch and the welding rod. The skill of the welder in applying the torch and the rod to form a secure and lasting joint is reflected in this smiling face. Knowledge and skill are necessary to assemble an aluminum chair, for it is made up of a number of separate metal pieces.

August, 1938; Page 121
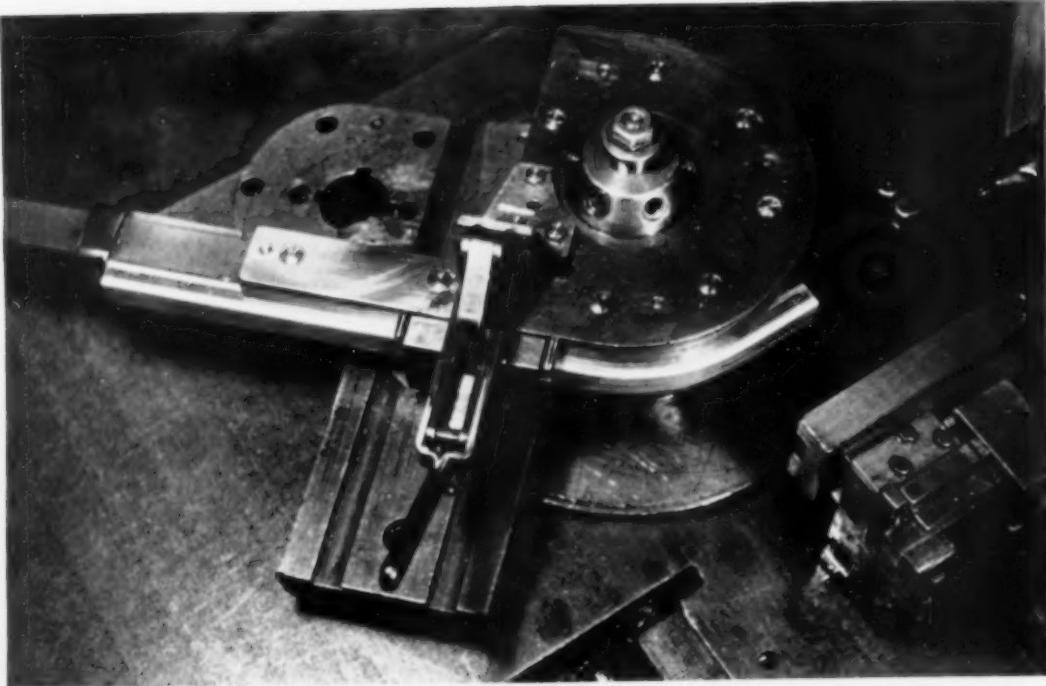
Manufacture is simplified wherever possible. It begins with lengths of aluminum tubing which are formed, in the initial operations, in dies or on simple bending brakes.

Frames which will eventually become backs and back legs are stacked after bending, ready for assembly in jigs, where further work is to be done. Aluminum furniture has been in commercial production ever since 1927, although some chairs were made on special order in 1924.
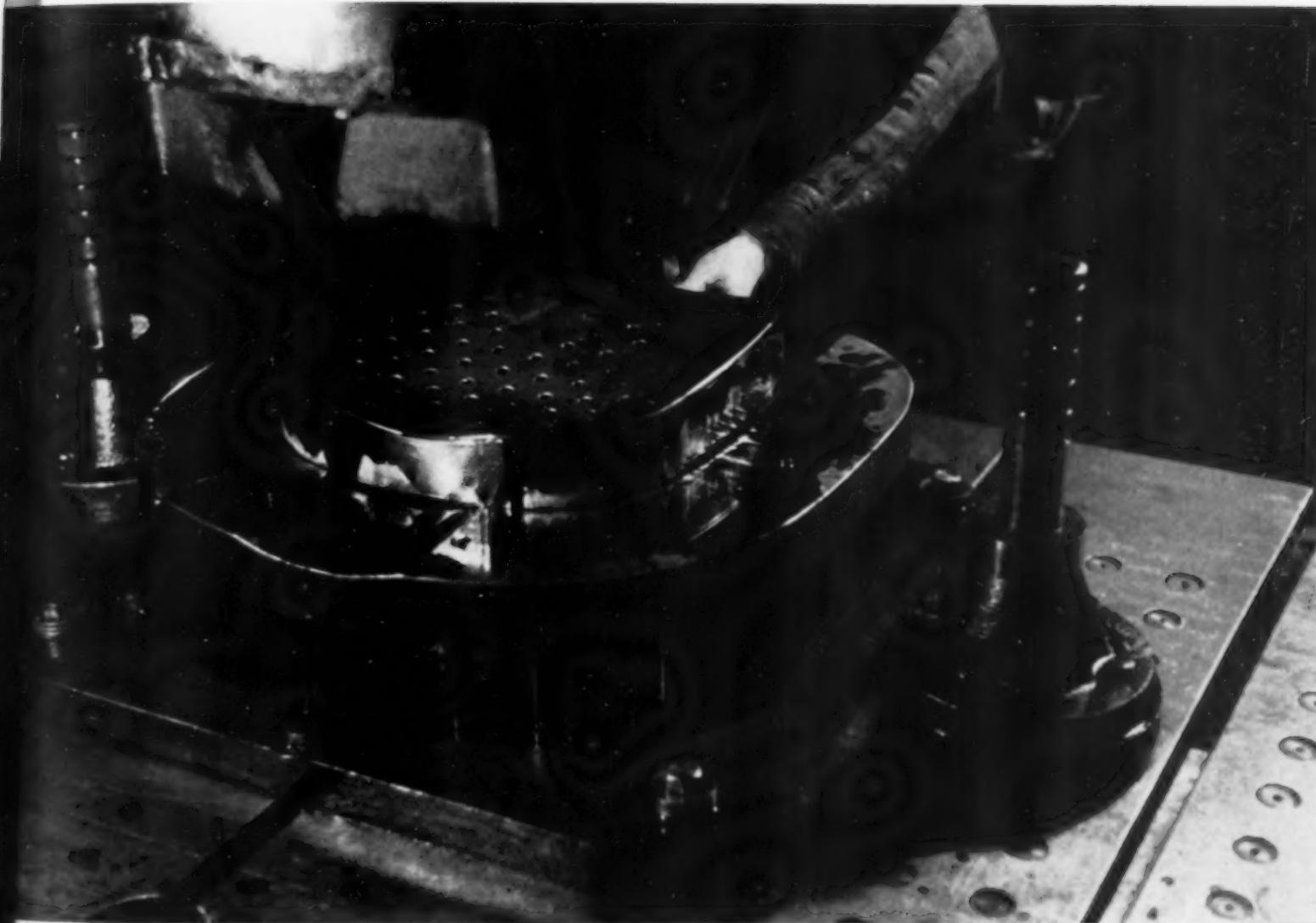
Executives' swivel chairs are provided with comfortable
upholstering and large perforated seat pans, which are
stamped out on a blanking press. After the stamping
operation, the excess metal on the sides is sheared off.

Welding flux looks messy, but is necessary for adhesion between the tubing and the metal from the welding rod which melts into the joint. Later this flux is removed.

Quick clamping jigs and fixtures hold the separate metal parts in place while the welder applies the torch to join them securely. After assembly the workman "tack welds" the back slats to the frame.
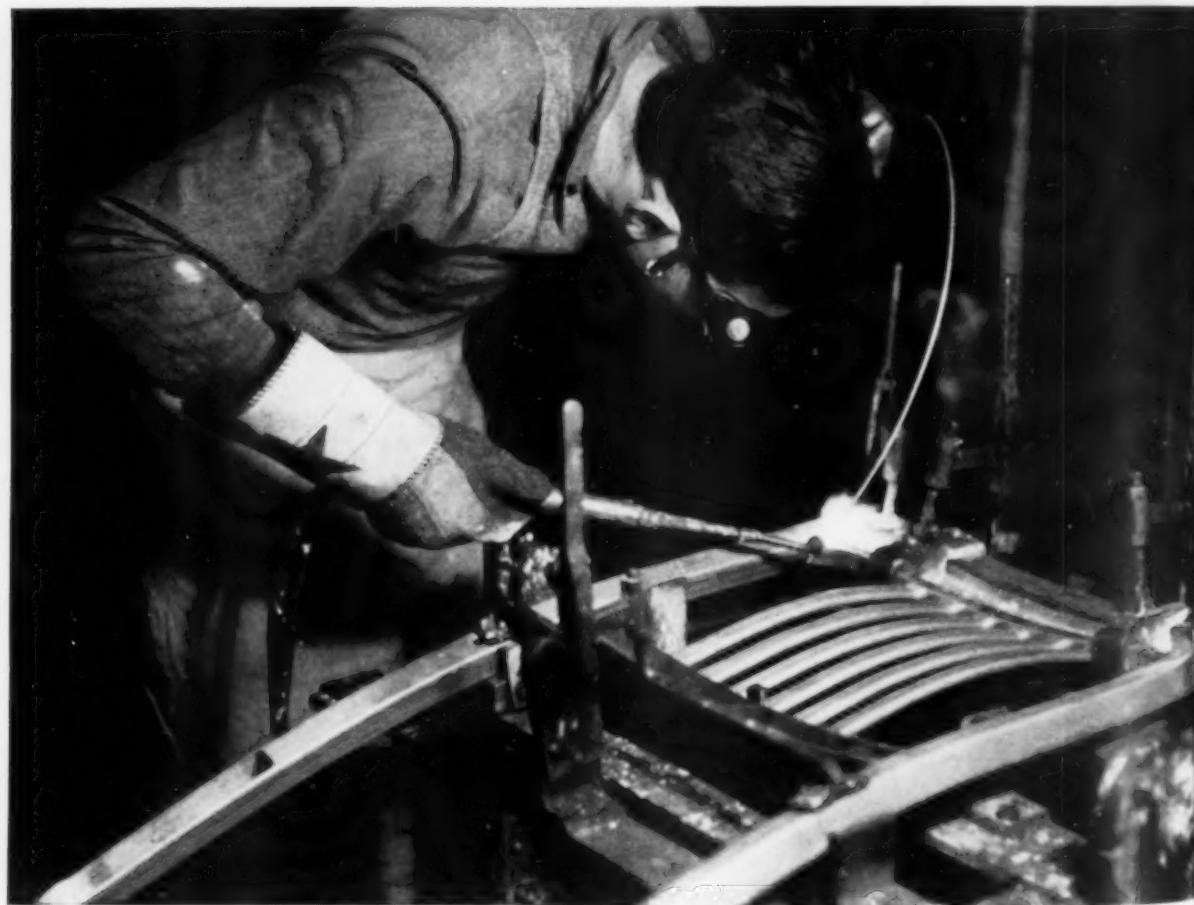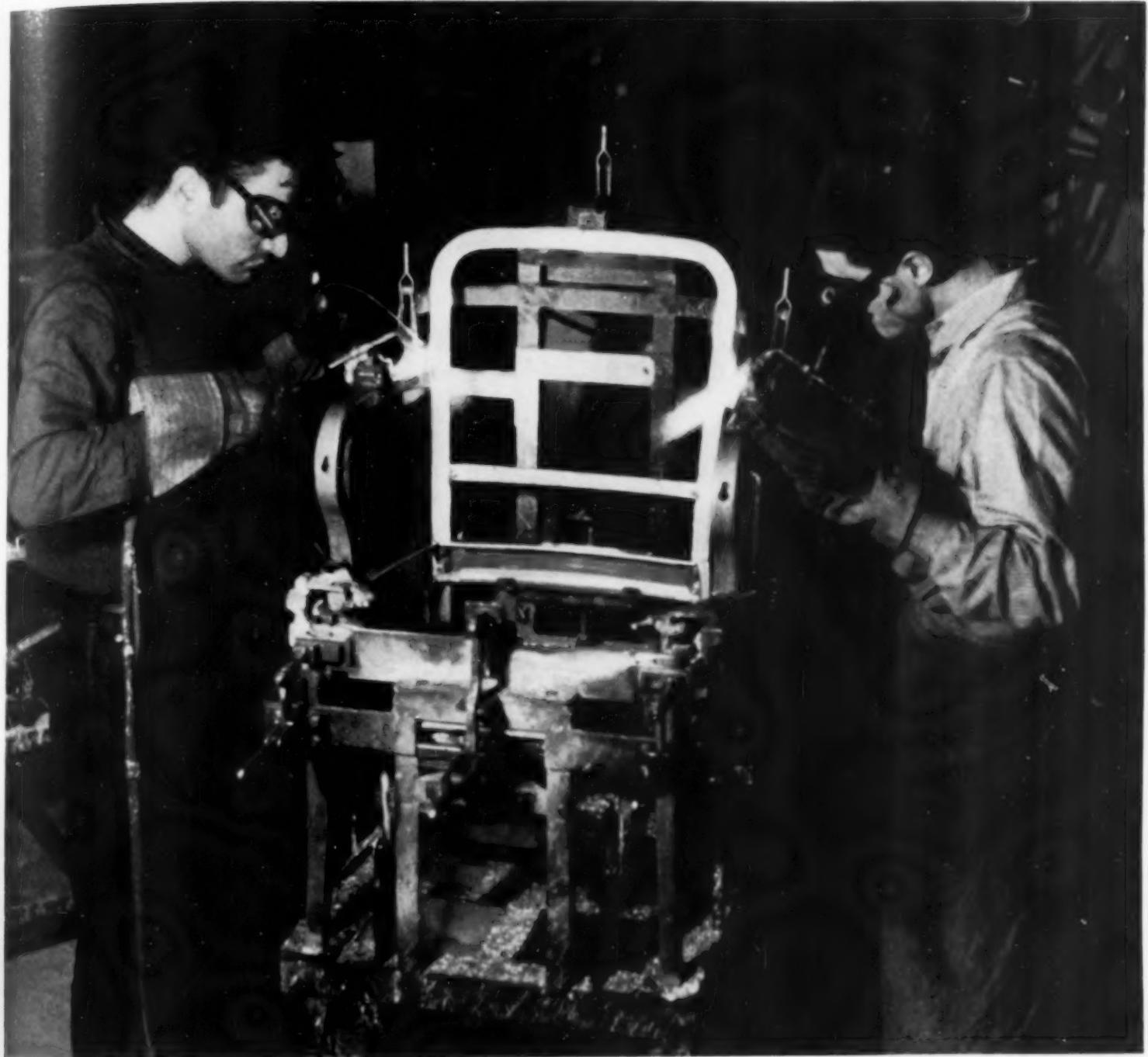
An elaborate jig assembles the entire chair from its
component parts and sub-assemblies. Mechanical
joints and reinforcements hold the back frame to the
rear of the seat frame, but all other joints are welded.
At right the workman is finishing a weld at the seat-
to-leg joint, one of the last of the welding operations.

Off comes the flux! The chair frame is lowered into a tank which contains a solution that washes the flux away, a mild solution that does not attack the aluminum or the welded joints.

Rough, ripply welds must be dressed down with a small portable grinder. Then the metal parts seem to flow into one another.

A buffing wheel for an attractive and unique
burnished finish on the completed metal chair.

August, 1938; Page 127
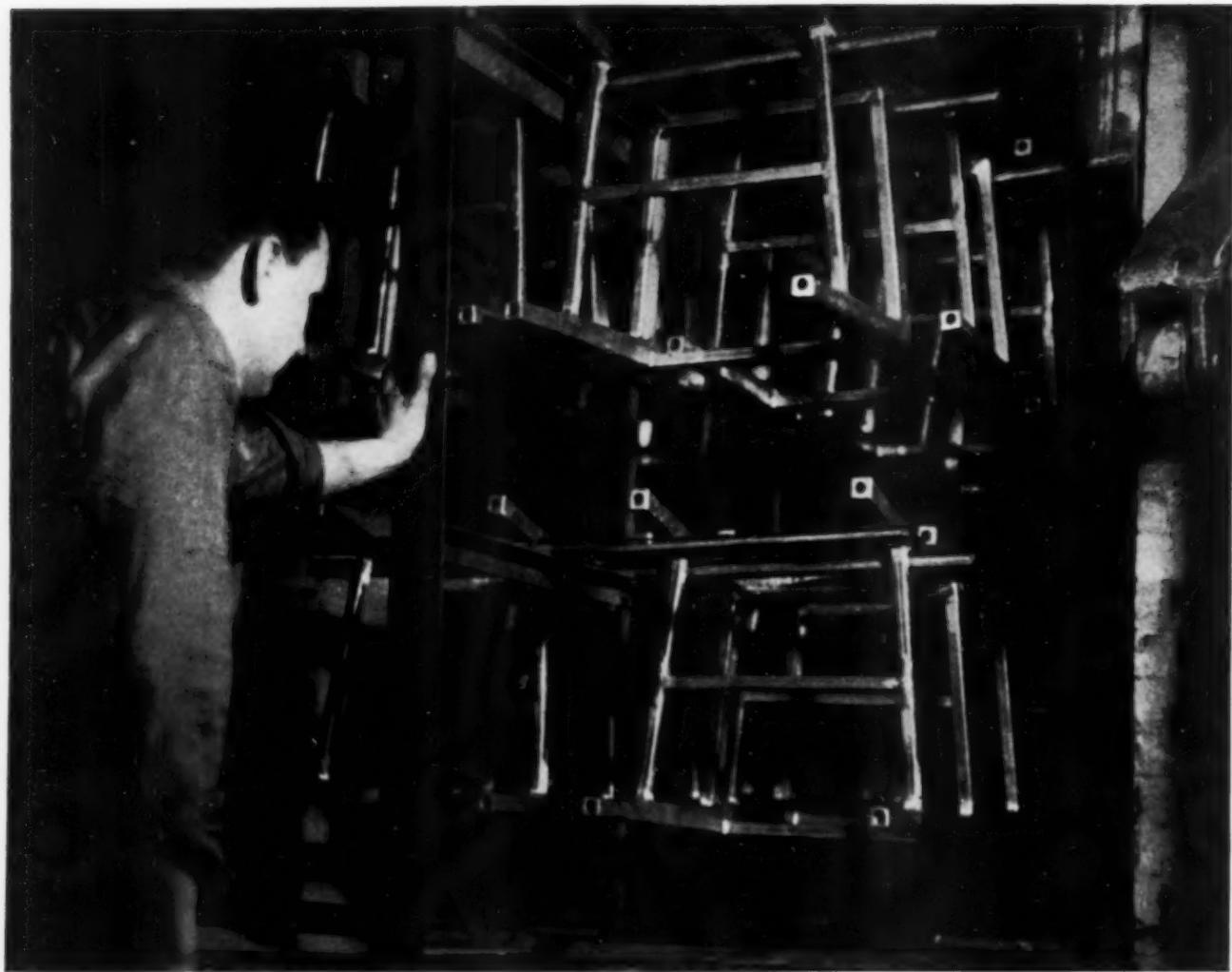
Aluminum alloys for easy working are soft and their strength can be increased by a simple heat treatment. A rack-load of chairs is here being pushed into the heat treating chamber. After such treatment a final hand finishing operation by fine abrasives gives the metal a finish like satin.

A hard, transparent, protective coating is applied to the surface by a spray gun, if a metallic finish is desired. For solid color finishes, the chairs are sandblasted and then sprayed. For imitation wood, the graining is applied by rubber rollers over the solid color. The seat pan, with its upholstering, is now firmly attached, and the chair is ready for shipment.

The application of modern welding technique is the reason for the durability of aluminum furniture. Welding makes of each unit one integral piece which will neither squeak nor creak, and which will retain its sturdy construction forever.

Copper in some alloy steels

By R. Harrison
Summary of paper for May meeting,
British Iron & Steel Institute

A RATHER COMPREHENSIVE STUDY of the effect of more copper than the usual 0.20 to 0.50% (added to increase the resistance to atmospheric corrosion) was made in an effort to develop a structural steel of high yield strength. Composition of the basis metal was therefore limited to low chromium and nickel steels. Carbon in most cases was in the range 0.20 to 0.35, although some very soft steels containing 0.05% carbon, 0.50% chromium, and copper from 1.62 to 5.20% were studied. The maximum temperature of reheating for rolling or forging was limited to 1920° F. to avoid melting any metallic copper formed in the scale and the consequent possibility of intercrystalline penetration by this liquid copper.

Mechanical properties of the steels were studied after they had been normalized in the neighborhood of 1500° F., and then tempered at lower temperatures (say 900° F.). The steels fell into two groups. Typical of Group I are the soft, 0.50% chromium steels, which did not harden appreciably after normalizing. Group II contains steels of air-hardening characteristics such as mild nickel-chromium steels (S.A.E. 3100 series).

Hardness of steels of Group I after normalizing depends largely on the carbon content. A copper compound or solution is precipitated from the alpha iron on tempering between 850 and 1100° F., and this further hardens the steel. This so-called "temper-hardening" reaches a maximum in a shorter time at the higher tempering temperatures, 5 hr. being required to secure it at 850° F., and 2 hr. at 925° F. This gain in hardness amounted to about 60 Brinell hardness numbers, and an increase in the copper content above 1.6% did not increase the effect. While the Izod number of all the very low carbon steels was over 99 ft-lb., the notched bar impact figure of the other steels temper-hardened at 930° F. was low or irregular, but considerably better values were obtained when temper-hardening was carried out at 1025° F. The properties of temper-hardened 2.0% nickel-copper steels were slightly inferior to the 0.5% chromium-copper steels.

Hardness of steels of Group II immediately after normalizing depended on their ability to air harden, and the above described effect of copper was masked by the softening due to the normal reactions of tempering. In other words, short reheatings tend to soften the normalized steels; on longer reheatings some temper-hardening may be noted. Better mechanical properties can therefore be achieved in small test pieces of hardenable alloy steels after ordinary heat treatments than after the addition of copper and the optimum precipitation hardening.

Some of the softer steels were oil quenched from the normalizing heats. The properties, as oil hardened and tempered, of the medium carbon steels containing chromium or nickel in addition to copper were generally improved by an increase in the copper content above the 1.5% necessary to give maximum temper-hardening. It appears that part at least of the nickel of such steels may be replaced by a similar weight of copper. Copper appeared to be without influence in increasing or reducing the susceptibility to temper brittleness. In all the microstructures examined the effect of copper in producing a fine grain size was noted.

Precipitation hardening, if it can develop equal mechanical properties, has an important practical consequence in that large and complicated forgings or castings may be hardened uniformly throughout the section and without introducing the danger of warping or cracking by quenching. However, the results of this study on forgings up to 3½ in. diameter indicate that the simple treatment sacrifices some of the properties obtainable, especially the Izod values. The advantage therefore lies with the ordinary method of quench hardening and tempering. The latter treatment is essential for obtaining high tensile strength. An argument for the temper-hardening treatment is that it should minimize the mass effect, but this advantage does not apply in sections of moderate size, since copper itself has a beneficial effect in increasing the depth of quench hardening. By temper-hardening alone, without the aid of some air hardening in normalizing, a tensile strength of over 110,000 psi. is not easy to get.

For moderate tensile strength the two treatments may be adjusted to give the same hardness and maximum load. In these conditions of equal hardness the tensile properties, including the elongation and reduction of area, are similar, but the notched bar impact figure in these tests is invariably considerably lower in the temper-hardened steel.

By Edward W. P. Smith
Consulting Engineer
Lincoln Electric Co., Cleveland, Ohio

The economics of

arc welding

AUTOMOBILE SALESMEN say that prospective purchasers seldom lift the hood — they assume that there is an engine underneath! In other words the mechanism is accepted as proven and suitable.

Much the same state of mind is growing up about welding. Those who are abreast of the times realize that, technically, the welded joint is proven. The remaining question is *cost*. How does the cost compare with alternative methods of joining?

True costs involve costs in use. However, such computations of true costs can only be made for specific cases with a great amount of accurate data in hand. In order to discuss one important item making up true costs, and for the sake of clarity, "welding costs" will be assumed to include the operations necessary to *(a)* prepare the sub-assemblies from stock steel, *(b)* weld all seams and *(c)* finish the welding in such manner as to be ready for subsequent manufacturing operations (or, if none are necessary, for delivery to the customer). For the sake of simplicity the cost of the raw materials (stock plate, shapes and bars) is not included, as it is fairly well fixed and not greatly influenced by welding technique, but the costs of supplies (electrodes and power) and labor are included. As will be shown by the following analysis, arc welding costs are notably reduced by use of (1) larger and more modern electric generators and (2) larger electrodes. Without marshalling facts and figures, it may be stated that large electrodes (other conditions being correct) will deposit the required amount of metal of high quality and ductility with fewer passes and thus result in less tendency toward distortion.

Large generators and large electrodes produce, therefore, welded construction of improved quality and at low costs. When quality goes up and cost goes down, can more be required of a process?

Before preparatory work can commence, a design must be made, and the designer selects the type of joint best suited for his purpose. Many factors enter his consideration, but we are only here concerned with the cost. How costs enter may be indicated by a brief statement concerning butt joints:

The plain butt joint is simplest to prepare — being merely squared edges, spaced a distance apart depending on thickness. This is quite appropriate for all thicknesses which do not exceed twice the penetration of the arc in use. (Welding from both sides must in such cases be convenient.) Preparation of the single V joint costs more than the plain butt joint and more electrode is required. Lastly, for the double V joint the cost of machining is higher yet, but it requires only half the amount of electrode for the same plate thickness. Economy for the very thick plates or slabs is effected by the single U or double U type of scarf.

If the designer has correct basic costs for machining and costs per pound of deposited metal, he can select the most economical type of joint from among those which satisfy other factors of design. He can also determine whether it will be less expensive to bend a plate rather than weld two pieces at a corner, or to use gas cutting rather than shears or other

mechanical means that are at his disposal.

Next is the matter of sub-assemblies. On this, obviously, only general statements can be made. But a study of assemblies and sub-assemblies, the ease of handling and accessibility of welds are all factors to be considered, and welding permits these sub-assemblies and assemblies to be so easily made.

Labor, Electrodes, Power

So much for the preparatory costs. The cost of welding, as such, is made up of three general parts: Labor (including overhead), electrodes, and power. Labor costs, in turn, depend largely on the operating factor and the speed of welding.

Many studies of actual conditions lead to the conclusion that greatest cost reductions can be made by increasing the operating factor — that is, by reducing the idle time when the operator for some reason or other is not welding. One important method of doing this is by proper jigs and fixtures, and the use of helpers to load and unload them. When working on simple parts, it is frequently easy to double the production per welder without undue fatigue, merely by providing him with an extra jig and one helper.

Another factor in reducing expensive labor costs is the matter of positioning the work so it is convenient and easy for the operator to weld. If he can always weld in the "down" position it will result in considerable increase in speed of welding and less fatigue.

Take for an example: A ½-in. fillet weld or corner weld made between a horizontal and a vertical plate would require, to control the molten metal, three passes with a comparatively light electrode and current. Net speed would be 11 ft. per hr. If such a joint were positioned so the intersecting plates were at 45° to the horizontal, thus forming a trough for the molten metal, the joint could be formed with one pass of a heavy electrode and the arc speed would be 26 ft. per hr.

The labor cost reduction is readily apparent.

The cost due to use of electrode is an important factor. Note that the statement is "the cost due to use of electrode," not "the cost per pound of the electrode." The size, the quality of deposit and the physical characteristics of the joint all depend upon the electrode.

The *size* of the electrode is a considerable factor in the ultimate cost. As a basis of discussion, assume that only the size of the electrode is changed; the deposition efficiency (that is, ratio of deposited metal to total electrode purchased), kind of joint, and all other items remain constant. Labor is assumed at $1.00 per hr., overhead is 100% on labor, power costs 2¢ per kw-hr., deposition efficiency is 66⅔%, and operating factor is 50%. Costs per pound of electrode deposited are then as computed in the table shown below.

Note that the use of a ¼-in. electrode in place of a $\frac{3}{16}$-in. one means a cost reduction of 42%. It is obvious that the largest sized electrode should be used, from a cost standpoint, that can be used on the type of joint in question.

Another item to consider in relation to costs

Effect of Electrode Size on Cost of Deposited Metal

	1/8 In.	5/32 In.	3/16 In.	1/4 In.	5/16 In.	3/8 In.
Ampères	110	130	150	250	325	425
Arc volts	24	25	26	30	34	38
Kilowatts at arc	2.64	3.25	3.9	7.5	11.1	16.1
Efficiency of set %	47	50	51	55	59	59
Kilowatts input	5.6	6.5	7.65	13.65	18.8	27.3
Theoretical electrode consumption, lb. per hr.	2.6	3.3	3.95	7.5	10.7	16.2
*Actual deposit, lb. per hr.	0.87	1.1	1.32	2.5	3.57	5.4
Interruptions per lb.	18	12	8	5	3	2
Dollar Cost per Pound in Deposit						
Labor	1.150	0.909	0.758	0.400	0.280	0.185
Overhead	1.150	.909	.758	.400	.280	.185
Power	.064	.059	.058	.055	.053	.051
Electrode	.150	.135	.127	.127	.127	.127
Cost of interruptions	.050	.033	.022	.014	.008	.005
Total	2.564	2.045	1.723	0.996	0.748	0.553

*Figuring 66⅔% deposition efficiency and 50% operating factor

of welding is the *performance* of the electrode. The cost per foot or the cost per pound of deposited metal (not the cost per pound of electrode purchased) is the important item so far as electrode is concerned. Perhaps it might be said that deposition efficiency and speed are the determining factors because it must be true that the physical performance of the electrodes to be compared is nearly the same. Data from a

careful test on two commercial electrodes in production on the same job are indicative.

In both cases ¼-in. electrodes were used with 340 amperes and 34 volts, and the efficiency of the generator was 59.5%. Tensile tests on metal deposited yielded comparable figures. Other measured and derived data follow:

	ELECTRODE A	ELECTRODE B
Weight of coating on electrode	22.2%	20.1%
Average electrode consumed per joint	1.60 lb.	1.56 lb.
Less stub ends	0.23 lb.	0.39 lb.
Net consumption	1.37 lb.	1.17 lb.
Gain in weight of welding (weight of deposit)	0.94 lb.	0.85 lb.
Per cent loss	31	27
Time per joint	7.9 min.	5.9 min.
Deposit per hr.	7.1 lb.	8.6 lb.

It is probably obvious that the higher rate of deposition (electrode B) is to be preferred, but the full effect of this on the cost is easily realized when calculating for a large job — as, for instance, one requiring 10,000 lb. of metal deposited in welds. Figuring costs of labor at $1.00 per hr., power at 2¢ per kw-hr. plus 10% to take care of idling losses, electrode at 8½¢ per lb. and operation factor of 50%, the costs without overhead for electrode A would be $4593 and for electrode B $3991, a saving for B of $602 or 6¢ per lb. deposited. Six cents per pound deposited is about 4¼¢ per lb. purchased, and this equals about half its first cost.

Cost of Power

Deposition of metal uses power and it is with this item we are next concerned. Power is supplied by special generators, driven usually by an electric motor.

In selecting a welding generator, in order to keep costs down, the most modern one available should be used. This type of equipment

has been under careful study and continual development. Take, for instance, some of the results on three models made by one of the leading American firms, when depositing 1 lb. from a ³⁄₁₆-in. electrode:

	TIME	KW-HR.
1927 model	2.5 hr.	2.2
1931 model	2.4 hr.	2.1
1938 model	1.8 hr.	1.6

Next is the selection of size of electrode. To do this intelligently it is necessary to know the application — that is, the size and type of joints and plate thicknesses, and also the percentage of total shop production for each kind of joint. These plate thicknesses can be expressed in terms of welding as "arc-amperes." Generators of different sizes have different efficiency curves, and if possible should be operated somewhere near their peak. Smaller generators have a peak at lower values for arc-amperes and of course are adaptable to small beads and thin plate. If the greater part of the work is done past the peak of a small generator, then a larger size should be used, as it will then work at a better efficiency. It is well to recall here that large electrodes result in reduced cost and larger electrodes require higher currents which are obtained at higher efficiencies in the large generators.

In calculating power costs, efficiency is the governing item. It is necessary, however, that this efficiency be that at the voltage and amperage existing *in the arc*. Manufacturers usually quote efficiencies at 40 volts and the figure would be 60% for a 110-ampere, 24-volt arc such as would be used with a ⅛-in. electrode, rising to 64 or 65% for a 300 to 400-ampere arc at 32 to 37 volts, used with ¼ to ³⁄₈-in. electrodes.

If the power input at arc voltage is not known, it may be calculated approximately as shown in the table at the foot of the page. The cost figures shown in the last line of this

Current Costs for Welding Generators

	Amperes				
	120	200	300	400	500
Voltage at arc	25	28	32	37	40
Kilowatts output at 40 volts	4.8	8	12	16	20
Efficiency at 40 volts, %	60	64	65	64	61
Kilowatts input at 40 volts	8.0	12.5	18.4	25	32.8
Correction*	1.8	2.4	2.4	1.2	—
Kilowatts input at arc voltage	6.2	10.1	16	23.8	32.8
Cost per hr. at 2¢	$ 0.124	$0.202	$0.32	$0.476	$0.656

*(40 - voltage at arc) x amperes ÷ 1000

table are plotted against amperes in the curve marked "Power" in the diagram below. Electrode costs in this diagram are based on data shown in the first table, figured at 8½¢ per lb., 100% operating factor and 66⅔% deposition efficiency. The curve marked "Electrode plus power" represents the summation of these two items. Parallel curves are drawn above this last at distances representing the labor rate per hour divided by the operation factor. Such a point on the diagram as A therefore represents the hourly costs for operation at 250 arc-amperes, $1.00 labor rate and 50% operating factor.

Straight lines at the left of the figure represent the simple relation between costs per hour (the vertical coordinates) and cost in cents per foot for various arc speeds. To derive the latter for conditions given above (point A) and, say, 20 ft. per hr., cross over from A horizontally to B and then down to read answer on bottom line, namely 14.5¢ per ft. This cost, it should be

remembered, does not include the overhead.

Position, type of joint, deposition efficiency, all govern the speed. These points were discussed briefly in the foregoing.

Finishing may be as simple as painting or adding a name plate. Painting involves accessibility, which may be a matter of preparation.

Stress relieving or heat treatment may mean special consideration in preparation and handling, as well as the question of collapse or deformation when the metal is hot and soft. Proper support must be given. There must be no completely enclosed parts; otherwise the expansion of the enclosed air would cause deformations if not serious trouble. All of these must be given careful thought and their interrelation thoroughly studied.

This final treatment or finishing process is related to preparation, the method of handling of joints or sub-assemblies and these in turn affect labor, electrode and material costs.

Costs in Cents per Foot of Bead, Based on 2¢ Power and 8½¢ Electrodes, for Welding at Various Labor Rates and Arc Speeds. Solution is shown for $1.00 labor and 50% operation factor, 20 ft. per hr. arc speed
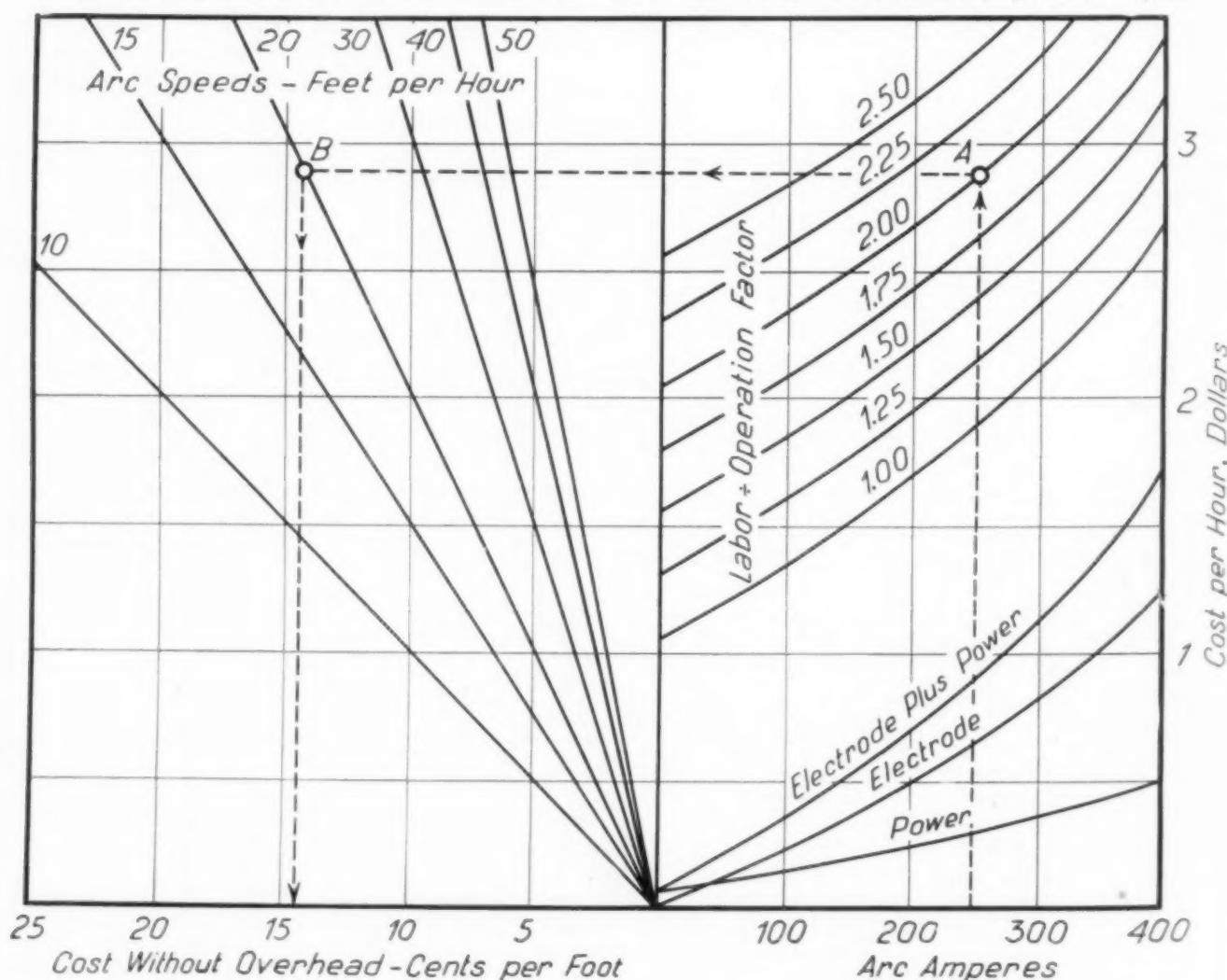
By Vsevolod N. Krivobok
Professor of Metallurgy
Carnegie Institute of Technology
Pittsburgh

Stable stainless steels

for cold working

and welding

IN THE ARTICLE IN METAL PROGRESS last month some remarks were made about addition elements to the plain chromium-iron alloys. It may have been observed that the amounts of these special elements, so briefly mentioned, are as a general rule quite small as compared with the amount of chromium present in the alloys. Consequently, as one would expect, these additions constitute merely an "improvement" — under some particular conditions — and their use is largely governed by economic considerations. Correspondingly, the tonnage of "modified" chromium alloys consumed yearly by the various industries is comparatively small.

We encounter, however, an entirely different situation when the amount of the added element is sufficiently large to modify the very nature of the alloy and to impart to it new characteristics. Of such alloys by far the most outstanding are those with added nickel; usually chromium is anywhere between 16 and 30% and nickel from 6 to 20%. These alloys are referred to, as is well known, as "austenitic alloys," because of their microstructure. It will be convenient to subdivide them, on the basis of their chemical and mechanical characteristics and also for commercial reasons, into several types:

Type No. 302; chromium 17 to 19%, nickel 7.0 to 9.5%, carbon 0.20% max.

Type No. 304; chromium 17 to 19%, nickel 7.0 to 9.5%, carbon 0.11% max.

Type No. 309; chromium 22 to 26%, nickel 12 to 14%, carbon 0.20% max.

Type No. 310; chromium 24 to 26%, nickel 19 to 21%, carbon 0.25% max.

The important characteristic of these alloys and equally important distinction between various classes or types is the variation in the stability of their microstructural constituent. Although these alloys after a simple heat treatment such as air cooling from 1900 or 2000° F. are composed of one constituent only (the phase called austenite, a solid solution of iron, chromium, nickel and carbon) these alloys are not truly stable in the physico-chemical sense. This means that if the alloys are subjected to cold work or to prolonged heating in a certain temperature range, new phases or entities appear in the microstructure with an accompanying modification in both chemical and mechanical properties.

It well may be that either of these methods of treatment will ultimately lead to the same phase equilibrium; at least that is theoretically possible. The intermediate stages, however, are different and it is important to understand and differentiate the changes brought about by cold working and those brought about by long time annealing. In other words, the user should realize the degree of "structural stability" possessed by these austenitic alloys.

Fairly recently it became established that "structural stability" is a function of the chromium, nickel and carbon content, and further, that it determines the physical properties after

various manufacturing processes. Consequently, austenitic alloys of different analyses, although belonging to the same group or type, exhibit vastly different combinations of mechanical properties, as should be readily seen from the table at the bottom of the column. Tests in this study were made on annealed sheet 0.038 in. thick, and the same after reduction in thickness by cold rolling 15%, 30% and 45% respectively.

Cold working of any of the alloys mentioned in the table is accompanied by the transformation of austenite into ferrite and, presumably because of this transformation, by the rejection of carbides, preferably at slip planes. Whether the *amount* of transformed austenite is the vital factor governing the properties is not yet established. Age hardening of the previously cold worked alloys establishes further changes in properties, pointing to the possibility that the amount of carbides either in or out of solution may also serve as an indicator of available properties. At any rate, whatever is the true reason, it is established that cold working of austenitic alloys causes transformation of the metal throughout the grains.

Through the regulation of analysis and processing of the metal (beginning with its melt-

Effect of Cold Work on Corrodibility of a Typical 18-8 Is Prominently Indicated by Long Time Tests. Corroding medium is cold 20% sulphuric acid

ing in the electric furnace) combinations of mechanical properties are now available which permit forming or drawing operations that have heretofore been considered impossible (or, to say the least, very difficult and uncertain). The examples of deep drawing, stamping and spinning shown at the 1937 Chemical Exposition in New York as regular items of production are ample proof of what can be done. As would be expected, the "ease" or "difficulty" with which the metal responds to the fabricating process, the degree of hardening that takes place during fabrication, also the magnitude of internal stresses locked in the metal, are all affected by composition.

In some circumstances the relief of internal stresses is essential and should be done immediately after fabrication. The temperature for stress relief is governed by circumstances, but in most cases it is desirable to have it as high as possible and to approach that of a full anneal — from 1950 to 2050° F.

Necessity for stress relieving is dictated by these possibilities: *(a)* Mechanical rupture of the heavily stressed (or heavily cold worked) sections, *(b)* diminished resistance to general or over-all corrosion, such as indicated by the laboratory test summarized in the curves above and *(c)* local, deep "stress corrosion," occurring only under certain combinations of degree (or magnitude) of stress and attack by corrosive media. A sample of the latter is photographed and reproduced in the half-tone on the next page.

Holding austenitic alloys at high tem-

Tensile Properties of Various 18-8's*

ANALYSIS			AMOUNT OF COLD REDUCTION			
C	Cr	Ni	NONE	15%	30%	45%
0.05	17.13	7.07	21,000	52,000	110,000	150,000
			137,000	161,000	180,000	197,000
			21.0	12.5	6.5	2.0
0.05	16.83	9.79	25,000	37,000	68,000	86,000
			87,000	107,000	126,000	152,000
			68.0	42.0	23.0	4.0
0.06	18.68	7.33	28,000	55,000	105,000	148,000
			127,000	154,000	177,000	199,000
			36.5	21.5	12.0	2.5
0.05	18.22	9.14	25,000	42,500	60,000	100,000
			86,000	102,000	128,000	155,000
			68.5	44.0	22.0	5.5
0.14	17.26	7.07	30,000	62,000	120,000	160,000
			136,000	176,000	206,000	238,000
			65.0	32.0	15.5	3.5
0.13	17.08	9.66	32,000	51,000	65,000	92,000
			90,000	112,000	137,000	158,000
			60.0	42.0	18.0	7.5
0.16	19.68	6.68	29,000	50,000	78,000	123,000
			114,000	144,000	172,000	200,000
			80.0	50.0	32.0	17.0
0.16	18.88	8.78	30,000	50,000	75,000	100,000
			99,600	120,000	150,000	173,000
			70.5	38.0	20.0	7.0

*Figures are respectively *(a)* load, psi., to produce permanent set of 0.0002 in. in 2 in., *(b)* ultimate strength, *(c)* elongation in 2 in.

peratures (from 800 to 1500° F.) will break down the austenite into ferrite and complex carbides. This action is *local*, manifesting itself in the most pronounced manner at the grain boundaries and, *in certain compositions*, requiring only a short time within above mentioned temperature range. This phenomenon is almost universally spoken of as "carbide precipitation" or "disintegration," and is so well known that to do more than mention it would be altogether unnecessary. Since carbide precipitation lowers the corrosion resistance and may take place very readily — at least, as was stated, in alloys of certain composition — even such a short time

Combination of Localized Stress (Internal or Applied) and Corrosion Caused Cracks to Penetrate Wall of This Tube Made of Austenitic Chromium-Nickel-Iron Alloy

at high temperature as for example in welding may prove sufficient to cause serious trouble in use. The effect of heat of welding should be mentioned purposely as an example of the *rapidity* with which certain alloy compositions may be affected, because it is obviously an important factor in construction and use.

The susceptibility of some austenitic alloys, otherwise so excellent in many important characteristics, to carbide precipitation is naturally a serious detriment which metallurgists have diligently tried to correct. The following methods, applied in accordance with circumstances, have solved, for all practical purposes, the just mentioned difficulty:

1. Lowering the carbon content to the permissible (commercially obtainable) values and at the same time properly adjusting the content of chromium and nickel.

2. Modifying the alloy composition by adding one of the elements vanadium, molybdenum, titanium, columbium or tantalum. Of the five mentioned, titanium and columbium, especially the latter for reasons that will soon be described, are considered the most valuable, because they effectively prevent difficulties caused by transformation of the austenite. Considerably less effective is vanadium. The austenitic structure of the chromium-nickel alloys is not changed by the additions of either titanium, columbium or vanadium, in amounts as are used commercially. The addition of molybdenum slows down, but does not prevent, carbide precipitation. Ordinarily — that is, unless the composition of the alloy is modified — molybdenum additions result in a duplex microstructure of the alloys, with some consequent changes in other characteristics.

3. Careful annealing at high temperatures and rapid cooling of the whole assembly which may have been subjected to local heating. This is an effective method, providing the heat treatment can be carried out properly and the assembly is to operate at room or only slightly elevated temperatures.

The effectiveness of the first method above is proven by observation, upheld by careful laboratory tests. By choosing a carbon content and adjusting the composition in chromium and nickel, the alloys become more "sluggish" insofar as precipitation of carbides at grain boundaries is concerned, and require a much longer time within the dangerous temperature zone (800 to 1500° F.) to cause the formation of a continuous network of carbides — the only kind producing grain boundary disintegration and thus being harmful to the corrosion resistance.

Thus the serviceability of these alloys is determined solely by the *conditions* of service; they could not and should not be considered for continuous service at the temperature range from 800 to 1500° F. in the presence of corrosive media. On the other hand if the alloy is to be subjected to heating within dangerous range of

temperatures for only a short time and then serve at room temperature, its use should be possible.

An example of such conditions would be joining by welding. If the material to be welded is relatively thin and, consequently, the dissipation of heat takes place rapidly, the welded assembly would be quite suitable to many industrial applications with mildly corrosive conditions, (using "mildly corrosive" in the sense as we use it in regard to stainless steels). Obviously each individual case should be separately studied and not only the corrosive conditions but the method of construction be taken into

In fact, their addition does not prevent, strictly speaking, the partial decomposition of austenite, nor does it arrest altogether the familiar precipitation of carbides. Partial decomposition (transformation) is proven by the appearance of magnetism in cold worked, or suitably treated, alloys containing columbium or titanium. Cold working also strengthens and hardens them; in fact alloys containing titanium work harden more rapidly than either the chromium-nickel alloy or the same with columbium. Likewise, the presence of carbides is observed under the microscope, deposited along the grain boundaries, but not necessarily in a network.
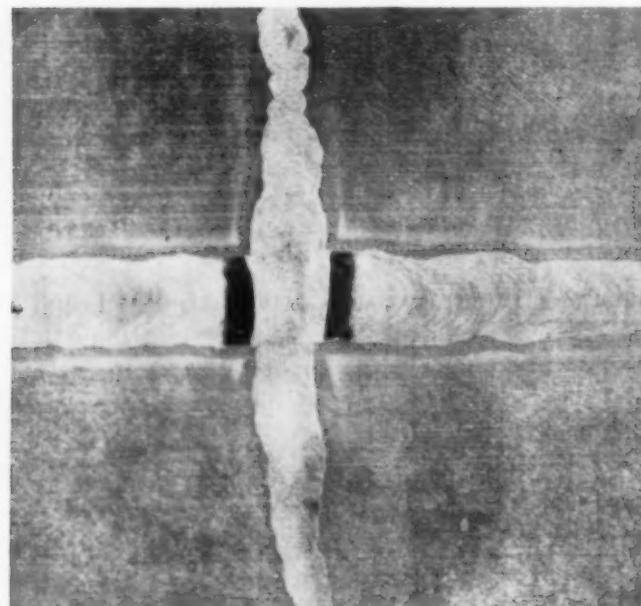
17.75% Cr, 9.97% Ni, 0.09% C, 0.47% Ti   19.9% Cr, 8.97% Ni, 0.08% C, 0.82% Cb

Effect of Cross Welding on Corrodibility of ¼-In. 18-8 Plates With Titanium (Left) or Columbium (Right). Welding rod cut from plates. Exposed to 10% HNO₃ plus 4% HF, at 140° F. for four 30-min. periods. Natural size

consideration. Welding of thin sheets may prove thoroughly satisfactory, but welding of the same thin sheet to some other part of considerable thickness may not. Again, such details as whether single or cross welding may be necessary in the course of construction should be carefully weighed.

When the chromium-nickel alloy has to be used within the temperature zone of carbide precipitation in the presence of corrosive media, the addition of either columbium or titanium, or in some cases vanadium, is obligatory. Usually these elements are added in amounts from 0.50% titanium to about 1.0% for the other two, depending upon the carbon content of the alloy. As was mentioned, these elements do not alter the structural constitution of the alloys.
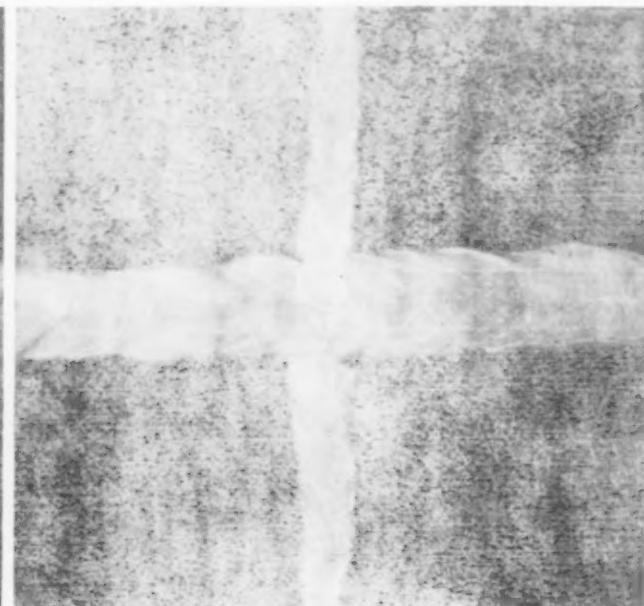
Nor does their presence seem to rob the grain boundaries of their ordinarily high resistance to corrosion.

Titanium bearing alloys contain, as a rule, fairly numerous non-metallic inclusions and appear somewhat "dirty" under the microscope. When the artificial but generally adopted method of testing the over-all corrosion resistance — namely, boiling nitric acid — is applied, the alloy's resistance will be found diminished, as compared to the alloy without titanium. While this effect may be important in some specific cases, ordinarily the resistance to general corrosion does not suffer enough to preclude the use of the alloy with titanium in many commercial applications.

The presence of columbium, although this

element is used in greater amounts than titanium, is less detrimental to general or solution corrosion. Although both alloys are quite effective in forestalling grain boundary attack, there is a very important distinction between them when they are to be applied in welded constructions. Ordinarily, welding rod of the same composition as the parent metal is used. In either arc or gas welding most of the titanium (in some cases as much as 80%) is oxidized and lost during fusion. Hence, not only the welding bead proper but also the areas immediately adjacent to the weld are composed of metal with very little titanium — in fact so little that

retains, after welding, its resistance to intergranular corrosion, acquired through the addition and presence of columbium. Intricate welding designs can therefore be carried out without the necessity of annealing, except for the purposes of stress relieving.

The third method recommended above to insure the expected performance on the part of the austenitic alloys after fabrication by welding is that of annealing. Simple as it may appear, this is obviously limited to vessels (or whatever it may be) of not too excessive size, or to material of not too great thickness. It is necessary not only to heat the metal to high temperature
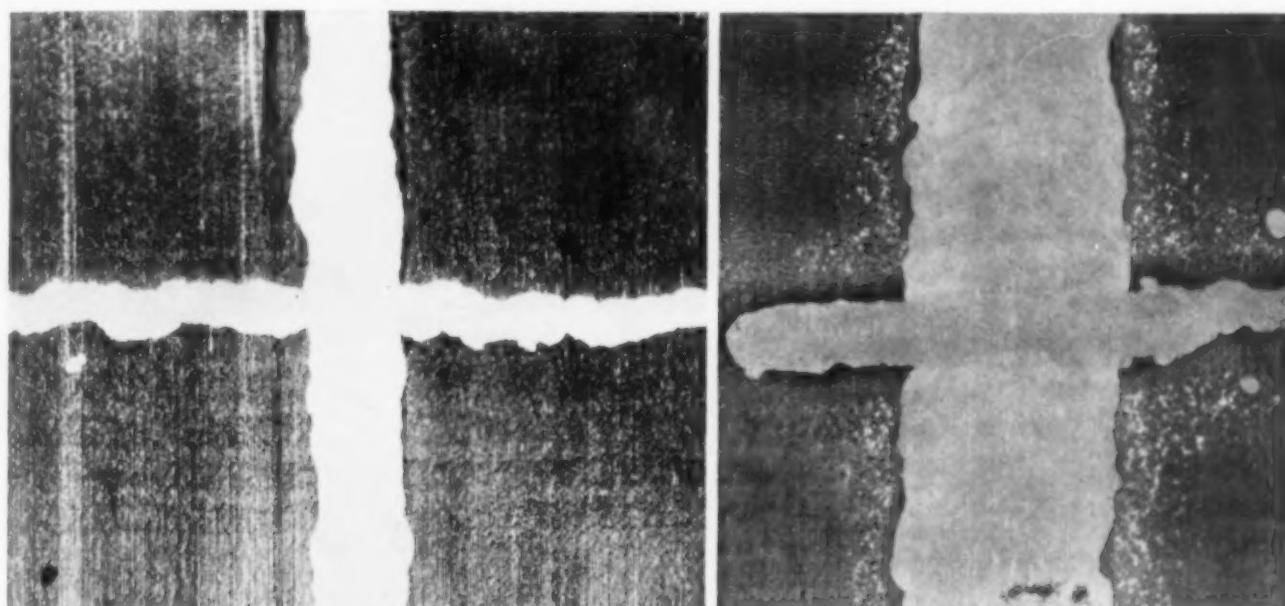
Plates ¼ in. thick; 24.52% Cr, 19.49% Ni, 0.07% C   Plates ⅜ in. thick; 24.96% Cr, 20.08% Ni, 0.09% C

Thicker Plates, Requiring Multiple Beads and Therefore More Welding Heat, Have Less Resistance to Severe Corrosion. Welding rods cut from plates welded; samples boiled in 15% HNO₃ plus 3% HF for two periods of four hours

its amount is insufficient to exert its useful influence, and if the article is to be used within the dangerous temperature zone, the harmful precipitation of carbides will then occur.

A very good illustration of this phenomenon can be furnished by cross-welding titanium bearing metal, as shown in the opposite view. When the first bead is laid out, titanium is lost. Upon the application of the second bead the heat of welding precipitates harmful carbides in the reheated areas. When, later, the sample is subjected to severe corrosion, this zone suffers a heavy attack or actual disintegration, depending upon the test that is applied.

On the other hand very little columbium is lost from the welding rod or from the areas adjacent to the weld. Consequently, the metal

(1850 to 2050° F.) thus putting the carbides into solution, but also to cool the metal rapidly enough to prevent re-precipitation of carbides upon cooling. The metal should reach 600 to 700° F. in no more than a few minutes, and such rapid cooling is not easily accomplished with large or complicated articles. However, unless cooling is rapid more harm than good will be done by annealing, and the fabricator should fully realize this danger.

Thus, the choice of the proper material for fabrication by welding is governed not only by the intended service or by the details of fabrication (such as cross welding) but also by the size of the proposed article and by the gage of the material to be used. Obviously if thick plates are to be welded
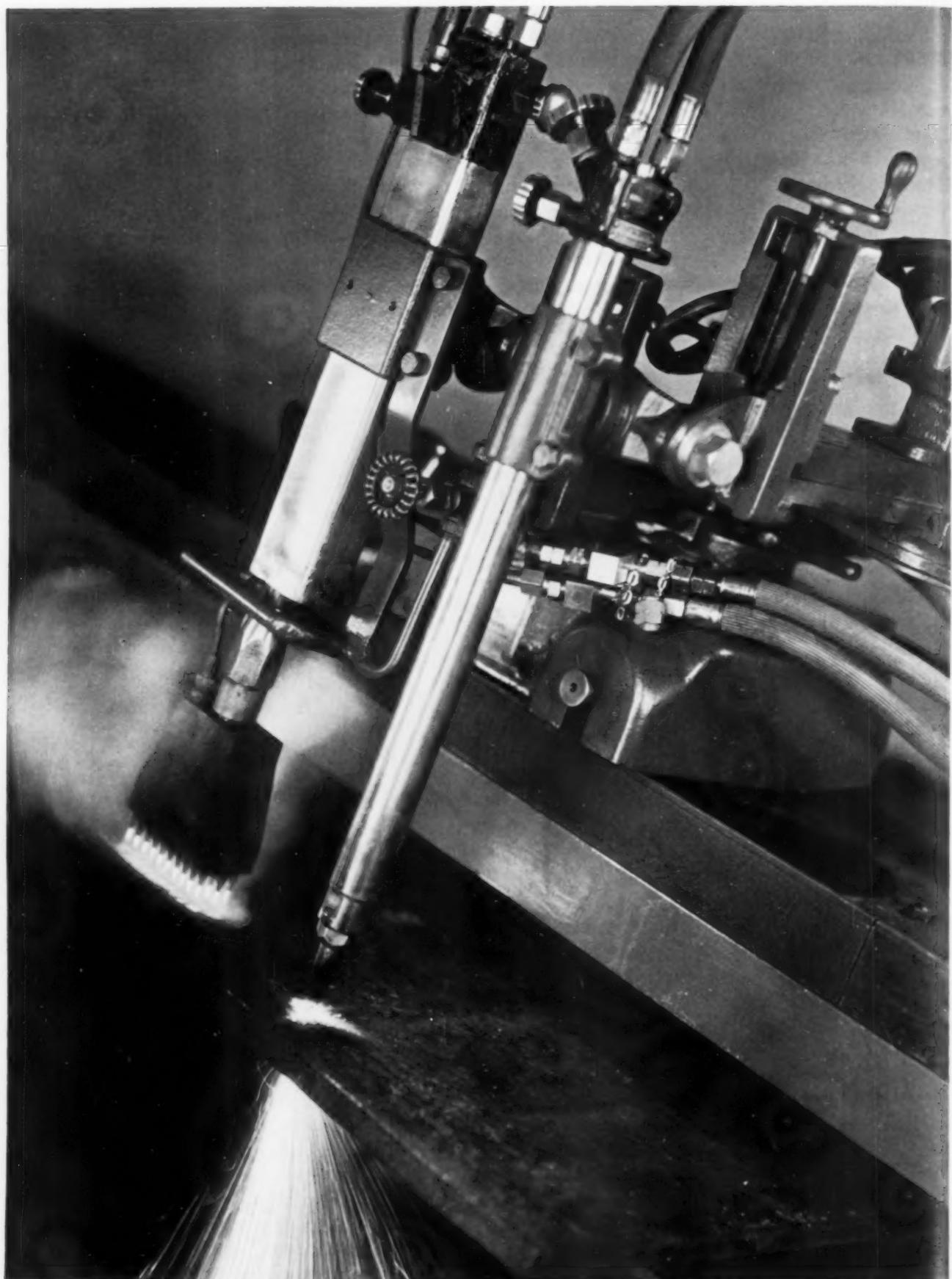
*Softening Flames From 30-Tip Head Following Cutting Blowpipe in
a Machine Operating on 1-In. Plate of Low Alloy Structural Steel*

Metal Progress; Page 140

By Herbert H. Moss
Development Engineer
The Linde Air Products Company
New York City

Flame softening of cut surfaces on strong steels

LOW CARBON STEELS without alloys — that is, the ordinary structural steel and boiler steel — are simply and economically shaped with an oxy-acetylene cutting blowpipe. The practice is so widespread as to be almost universal. Nevertheless, doubts have been expressed, as to whether the operation and its sudden heat would harm the steel along the cut surface, and a number of studies have been made which should finally settle this point.

Perhaps the most extensive of these investigations was made by J. H. Zimmerman of the faculty of Massachusetts Institute of Technology, and reported to the International Acetylene Association in 1934 and 1935. He compared the surfaces left on ½-in. standard structural steel plate by five cutting procedures, namely, machining, shearing, friction sawing, hand torch, and machine flame. Later these studies were extended to heavier thicknesses and other specifications such as bridge steel (A.S.T.M. specification A-7) and flange steel A-70. His conclusions on these low carbon steels are worth repetition:

"1. The disturbance of the hardness and structure of the structural steel plate tested is less severe in flame cutting than in either shearing or friction sawing.

"2. Machine flame cutting does not appreciably affect the toughness of the metal adjacent to the cut surface; hand-torch cutting definitely improves the toughness of this metal; shearing or friction sawing decreases the toughness slightly.

"3. Ductility of the structural plate tested, as determined by the cold-bend test, is less seriously affected by hand-torch cutting than by either shearing or friction sawing. Machine flame cutting may even be beneficial in this respect."

These statements gave a sound basis to the general practice in the steel works. As expressed by L. M. Curtiss of Lukens Steel Co. to the same Association in 1931 in a paper on "Machine Gas Cutting of Heavy Plate," the physical and chemical changes produced by the cutting operation leave a thin hardened zone on the outside edge, the penetration of which is usually superficial. With ordinary steels of 0.30% carbon and under, no particular difficulty has been experienced in the Lukens plant in bending or fabricating, whereas with high carbon and alloy steels, the precautions of annealing or machining should be taken in order to remove the hardened edge.

So much for the plain carbon mild steels. In recent years a number of stronger steels have been widely employed for large structures and machines. It soon became evident that these were not reacting in the same manner. The matter was brought to a head early in the fabrication of steel for the two large bridges at San Francisco. Leon S. Moisseiff, consulting engineer for the Golden Gate suspension bridge, reported adversely on flame cutting of the so-called silicon structural steel, and an investigation by the American Bureau of Welding led to the conclusion that a flame cutting blowpipe, as ordinarily used, was not a satisfactory tool for the grade of steel in question.

It may be stated immediately that localized heat treating provided an economical means for overcoming the trouble, and handy equipment was devised for doing this either immediately ahead or immediately behind the cutting flame. However, a broad investigation of the problem seemed to call for a study of the following points:

(a) The demarcation as to analysis where real damage begins in fabrication or in use.

(b) Inexpensive means to correct it, easily applicable to shop or field practices.

Point (a) cannot be gaged by a single yardstick, but for our present purposes the hardness and bending ability of the cut surface will be illuminating.

Hardness is a good measure of tensile strength. It is also known that machining (as done in structural shops) generally is classed as "difficult" as the Brinell hardness approaches 300; probability of surface cracking enters as the hardness approaches 375 Brinell, beyond this is the brittle range. Due to the shallow depth of the hardened zone under investigation in these tests, hardness readings were made with the Rockwell C scale for the hardest surfaces and with the Rockwell B scale for flame softened surfaces. In the field, in some cases, the portable scleroscope was used. All were then converted to Brinell readings.

Bend tests may be made on a specimen, approximately square in cross-section and 12 in. long, so placed that the flame-cut surface will be on the outside of the bend. A.S.T.M. specifications generally require no cracks in a 180° cold bend, either flat or around a pin of specified diameter, depending on the quality of the plate and its thickness. This may be termed the "cold bend test" and noted as "c.b." in the table below. Another recommendation is to bend slowly in a press in a standard fixture and measure the elongation of the stretched surface when cracks start. This may be termed the "free bend test" (f.b. in the table). The writer believes that a better test is an "anvil bend" (a.b.), performed as shown in the sketch, hammering with 8-lb. sledge, full arm swing. The measure of ductility for the surface under test was the angle of bend at the moment of rupture at the crown of the bend. While this test is somewhat at variance with standard pin bend tests, it is regarded as a more drastic test of metal surfaces, particularly of the marginally affected zones under the cut surface.

Data given in the table are averages resting upon production operations with oxy-acetylene flame cutters. Temperature of the steel when cut was that of shop or laboratory, ranging from 50 to 80° F. Increased hardening can be expected when the steels are cut at lower temperatures and vice versa. Thickness of plate, in most tests, ranged from ¾ in. to 1½ in.

Effect of Cutting and Flame Softening of High Strength Steels

Grade and Significant Analysis	Parent Metal		Gas Cut		Flame Softened	
	Hardness	Bend	Hardness	Bend	Hardness	Bend
Carbon structural C 0.25; Mn 0.45	137	180°	218 max.	170° to 180°c.b	—	—
Medium carbon (SAE 1040) C 0.40; Mn 0.55	153 to 170	180°	370	—	—	—
High carbon (rails) C 0.70; Mn 0.75; Si 0.25	222 to 259	34° to 43°a.b.	532 to 639	0° a.b.	235 to 325	3° to 62°a.b.
Silicon structural (low Mn) C 0.30; Mn 0.75; Si 0.25	149 to 180	180° c.b. 40 to 56% f.b.	187 to 522	38° to 180°c.b. 8 to 10% f.b. 10° to 38°a.b.	153 to 212	180°a.b.
Silicon struct. (medium Mn) C 0.30; Mn 1.25; Si 0.25	165 to 223	180°c.b.	241 to 444	0° to 56°c.b.	179 to 228	180°c.b.
Medium manganese C 0.30; Mn 1.50; Si 0.25	150 to 200	180°a.b. 38 to 46% f.b.	203 to 555	0° to 72°ab 8% f.b.	179 to 285	180°a.b.
Silico-manganese C 0.40; Mn 1.50; Si 2.00	140 (annealed)	—	469	—	241	—
Nickel structural C 0.30; Mn 0.70; Ni 3.25	214 to 240	180°a.b.	430 to 539	5° to 44°a.b.	179 to 237	180°a.b.
Nickel chromium C 0.30; Ni 3.25; Cr 1.25	196 (annealed)	—	455	—	262	—
"Cor-Ten" C 0.10; Si 0.75; Cu 0.40 Cr 0.75; P 0.12	132 to 175	180°a.b.	132 to 258	94°to 180°a.b.	145 to 200	180°a.b.

As shown in the table, the low alloy structural grades of steel, with few exceptions, are seen to be in an extremely vulnerable position as far as concerns hardness and bending qualities of flame-cut surfaces. This explains why it has been necessary for the fabricating shops to machine or grind such surfaces in these grades in order to prevent subsequent damage. Where dimensions permit, parts have been preheated or annealed after cutting, or, as is often done in the steel mills, sandwiched between hot slabs or ingots. Similar remedial practices are employed for the plain high carbon steels. These supplementary operations, w h i l e effective, add substantial increments of cost.

Commercial apparatus developed by The Linde Air Products Co. to perform the necessary heat treatments are shown in accompanying half-tones. A rapid input of heat was necessary and the oxy-acetylene flame provided this. The necessary *quantity* of heat was obtained by banking numerous flames in suitable blocks which could be so placed about the cutting flame as to effect the desired heat treatments.

"Anvil Bend Test" Used to Determine Ductility of Flame Cut Surfaces

Simultaneous operations required only the adjustment of heat quantity to effect a specific treatment at a specified cutting rate. The several units are assembled from standard equipment with the exception of the blowpipe mountings which are best worked out at the place of application.

Flame softening heat is provided by either 7-flame or 30-flame water-cooled heads and these are connected by straight or angular fittings to blowpipes providing adequate volumes of mixed gases.

For straight-line mechanical applications for usual fabricating shop purposes, a variable speed, portable propelling unit is employed to move the apparatus over the work. Various combinations of flame assemblies and heat areas can be obtained by grouping the multi-flame heads, and by the further expedient of blanking out one or more tips with plugs. When

it is desired to soften one side or face of a cut or kerf by post heating, one 30-flame head usually suffices where the thickness of the metal does not exceed $1\frac{1}{2}$ to 2 in. If the cut is through the body of the plate and it is desired to soften both sides or faces of the cut, two 30-flame heads should be used, one operating on either side of the kerf.

As the gage of the metal increases, it becomes more and more difficult and expensive to carry out the simultaneous operation inasmuch as it must be performed by soaking the heat into the metal from its upper and lower surfaces. It is better to apply the localized heat treatment directly onto the surface of the cut after the parts are separated. This operation is likewise performed progressively. For such treatment in heavy slabs, economy may be obtained by banking two or more heads abreast. A set-up for such work is indicated in the view on page 145.

The sketch on page 144 indicates some of the possibilities of this process as to the heat cycle imposed on the metal at and closely adjacent to the cut. The curve labeled "plain flame cutting" indicates that this metal is cooled very rapidly from near the melting point to below the critical temperature after the cut is finished, since the cold metal of the plate abstracts heat rapidly. This is a virtual self-quench, and is responsible for the hardened surface. When the cutting flame is followed by a block of softening flames as shown by the full page engraving at the head of this article, which heat the top surface locally to a faint visible red (say 1000° F., well below the critical point), the conditions are as indicated by the curve marked "flame softening by tempering." Where such post heating is employed, the heat generated by the cutting operation elevates the temperature of the metal in the cut surface to the melting point, whereupon it drops rapidly, passing quickly through the Ar_1 temperature to a point well below where it is again elevated by the post heating to a predetermined red heat,
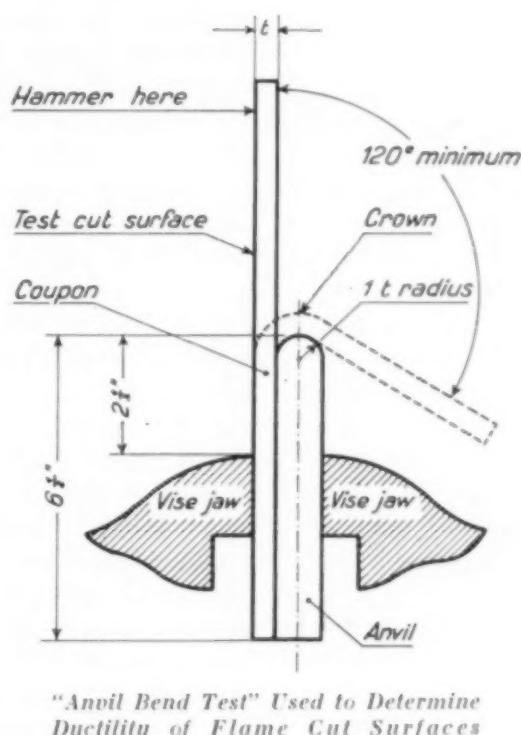
Water-Cooled Block Containing Seven Heating Tips, and Necks for Attachment to Standard Welding Blowpipe

from which point it is allowed to cool to normal temperatures.

For air hardening grades, such as the nickel and silicon and manganese structural steels, it is essential that the post heat do not exceed the critical point. The heat treatment indicated by this curve allows the hard constituents to form immediately after the cutting flame has passed, whereupon they are tempered or softened by the subsequent heating operation.

For steels which are more highly resistant to tempering, such as some of the low alloy chromium-nickel and chromium-molybdenum steels, the time-temperature conditions for effective tempering are so critical that it is more expedient to anneal, followed by a sub-critical heat; this has been found effective in producing substantial reductions in the hardness of plain gas-cut surfaces. The curve marked "flame softening by annealing" and "secondary tempering for alloy steels" approximates the time-temperature conditions for a treatment of this character. An instrument set-up suitable for this double treatment, applied to the edge of a

thick plate, is shown at the bottom of the opposite page.

Heating the top side of the plate has been successful for plates up to and including 1½ in. thick where it is desired to meet the requirements for bending laid down by standard specifications. For a lower degree of softening this thickness range may be extended to 2 in. or even to 3 in. The cost is mainly a matter of increased gas consumption, inasmuch as the operation is carried out simultaneously with cutting and therefore little extra labor is involved. Volume of oxygen and acetylene for softening ¾-in to 1¼-in. thick steel by simultaneous treatment may be estimated at 2 cu.ft. of each gas per linear foot of cut for each side of the kerf softened.

In thicker plates or shapes, up to 4 in. say, it may be possible to arrange fixtures so the steel can be heated simultaneously from top and bottom. However, due to mechanical difficulties in under-reaching a plate, this type of treatment is more or less confined to edge cutting of plates.

Arrangements for heating the kerf itself, either singly or doubly as on page 145, come into play for heavy slabs. Preferably the cut surfaces should be reheated before they cool to room temperature, particularly sensitive grades, in order to prevent microscopic surface checking or visible cracking. Equivalent surface areas can be softened with approximately one third to one half less gas than when only the top surface is post heated. However, the treatment is non-simultaneous with cutting and the costs involve both gas and labor. The operation is usually conducted at a faster rate of speed and therefore the total cost by this method may be only slightly greater.
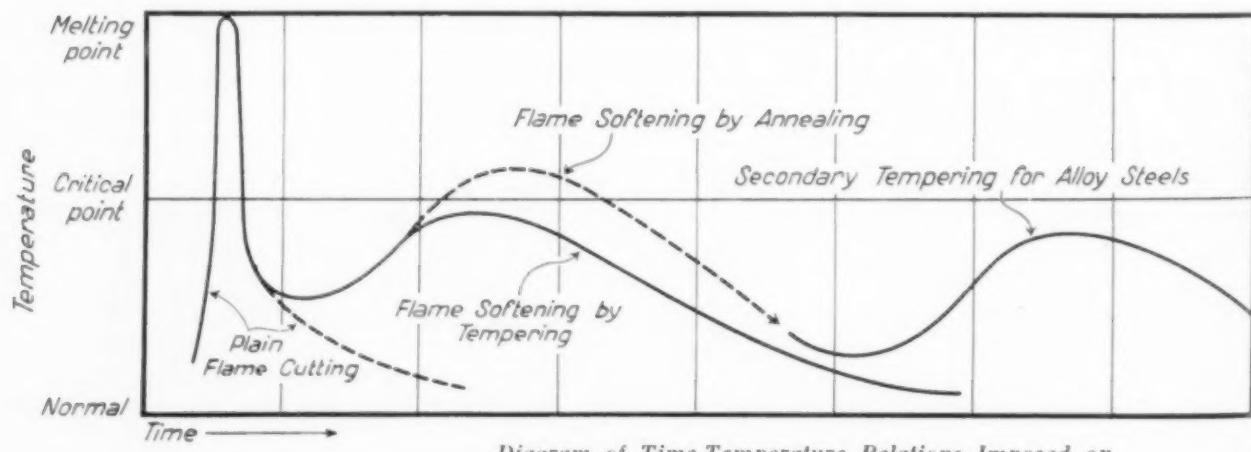

Diagram of Time-Temperature Relations Imposed on Flame Cut Surfaces, Post Heated in Various Ways

Measurement of Results

The degree of softening produced by flame softening processes in the grades of steel listed in the table on page 142 is shown in the last two columns. Hardness has been prevented or kept within reasonable limits. For the structural grades in both the quench hardening and air hardening groups, the residual ductility in the cut surfaces, after softening, is of the same order as that of the parent metal, having withstood either the standard cold bend test or the hammer bend test without cracking. In some cases the residual hardness is slightly lower than that of the rolled material.

In the plain high carbon steels and the silico-manganese and nickel-chromium alloy steels, which were treated non-simultaneously, the hardness of the cut surfaces has been reduced nearly 50% by a single high speed tempering pass, or to such degree as to be readily machinable and to overcome the possibility of cracking during cooling. Modification of this simple treatment should lower the hardness still further.

Macroscopic and microscopic tests of the heat affected zones of plain and flame softened cuts were made by Union Carbide and Carbon Research Laboratories, in the nickel, silicon and manganese structural steels to ascertain the depths of these zones and their structural constituents.

The depth of the zones heated to temperatures which were high enough to alter the internal structures of the steel and thus change their physical properties was found to approximate 0.04 to 0.08 in. in 1-in. thick steel, the narrow depth applying to structural silicon steel, an intermediate depth to structural manganese steel and the maximum depth to structural nickel steel. These depths are not materially altered in the heavier gages.

The hardness in these affected zones graduates to the normal hardness of the unaffected parent metal and therefore the depth of injurious hardening was somewhat less than that reported above. Plain flame cutting in these grades carburizes the surface of the cut to a depth of 0.002 to 0.003 in., and the cooling that follows cutting is rapid enough to affect the structure in a surface zone approximately 0.015 in. wide in which the hardness and the structure gradually vary from the very hard conditions wherein the structural constituent is martensite, to the original structure consisting of pearlite

and ferrite produced in the normal cooling from rolling temperatures.

The size of the structural units in the hardened zones was much smaller than in the parent metal. In other words, flame cutting refined the grain.

Flame softening tempers the martensite and eliminates the structure representing the brittle condition. As the flame softening treatment is carried on below the critical point of the steel, neither the microstructure nor the physical properties of the underlying steel having normal ferrite and pearlite structure are affected.

It was therefore the laboratory's conclusion that the steel in the heat affected zone which was flame softened by post heating is given a desirable combination of hardness and ductility, tempered to a practically ideal condition.

Drift Tests

At the recommendation of C. F. Goodrich, chief engineer of American Bridge Co., flame softened edges in a representative group of high tensile structural steels were subjected to drift testing, inasmuch as certain specifications

Instrumental Set-Up for Giving Duplex Heat Treatment to Cut Edge of Heavy Slab After Cut Is Finished and Scrap Removed. Leading pair of flame blocks reheat surface above critical, and trailing block then reheats and tempers the annealed surface (considerably cooled in the interval)
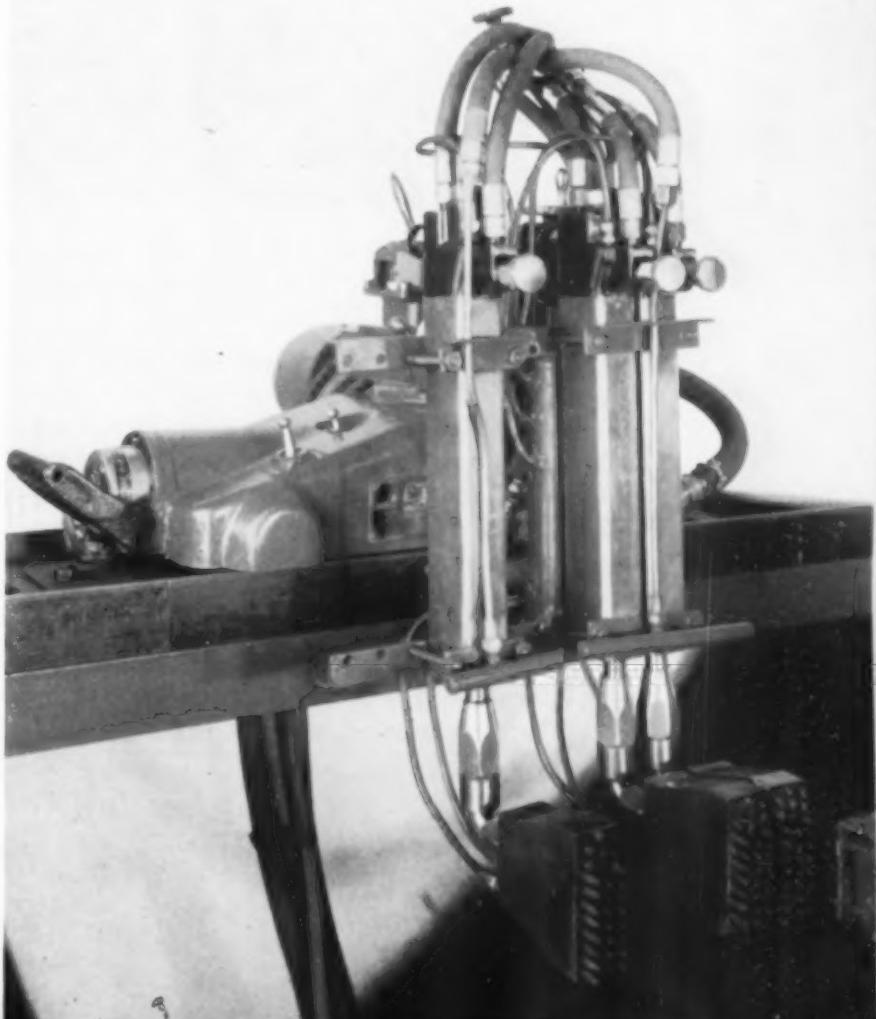
require this. In substance, the test requires that punched or drilled holes spaced approximately two diameters from a planed edge shall stand drifting until the diameter is enlarged 5% without cracking metal.

Accordingly, a piece of $\frac{7}{8}$-in. plate, 16 in. square, was prepared of structural manganese steel, structural silicon steel and structural nickel steel. In each piece edge No. 1 was sheared, edge No. 2 was sheared and planed $\frac{1}{4}$ in., edge No. 3 was plain flame cut and edge No. 4 was flame cut and flame softened simultaneously.

Three $\frac{13}{16}$-in. holes were drilled at the quarter points along each side and 2 in. back from the edge. Drift pins having diameters progressively increasing by $\frac{1}{8}$ in. were then forced through the drilled holes with a steam hammer. Results are shown in the halftone below. The arrows point to cracks. The planed edges and the flame softened edges withstood drifting to $1\frac{9}{16}$ in., or approximately 100% enlargement without cracking, at which point the test was stopped. Other types of surfaces were definitely less ductile, although the worst

	Flame Cut	Flame Cut and Softened	Machined
Nickel steel • Yield point	69,900	68,700	68,200
Ultimate strength	87,800	99,000	100,700
Elongation in 18 in.	1.7%	13.0%	14.7%
Silicon steel • Yield point	45,000	52,300	45,400
Ultimate strength	72,000	88,100	85,700
Elongation in 18 in.	3.8%	15.6%	17.1%
Manganese steel • Yield point	52,600	58,300	52,500
Ultimate strength	69,400	92,200	92,800
Elongation in 18 in.	1.5%	16.2%	18.0%

flame softened edges are seen to be in good agreement with those having planed edges, in contrast to the flame cut bars which failed at reduced loads and ductility.

Elongation and reduction of area of the flame softened bars are of the same order as that of the planed bars, while the plain flame cut bar has an abrupt fracture with negligible reduction of area.

From a consideration of the test results investigating the hardness, ductility by slow bend or hammer (anvil) bend, microstructure, drifting and tension on large-sized bars, it is
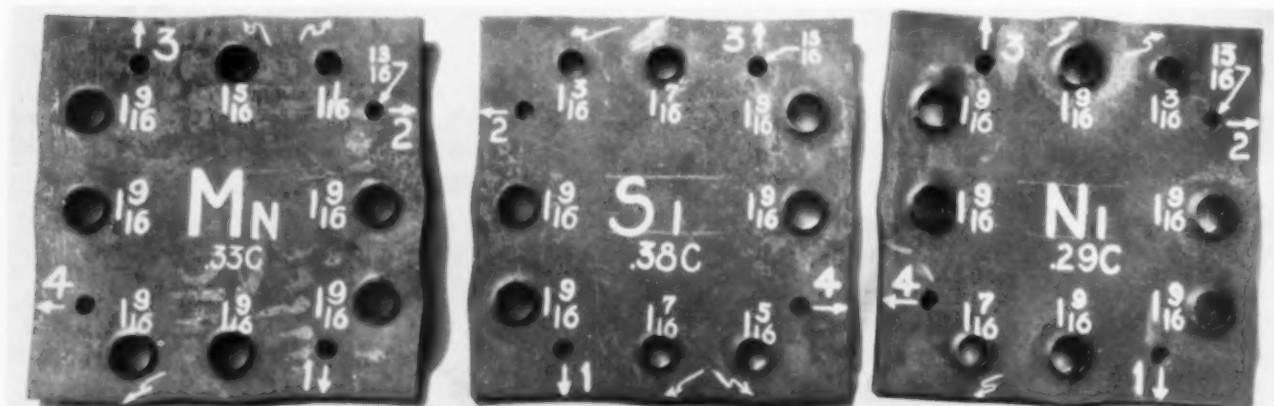
Drilled Holes Were Drifted 100% Without Edge Cracks on Either Flame Softened Cuts (4) or Planed Edges (2) in High Tensile, Low Alloy Structural Steel Plates

of them managed to withstand up to 40% enlargement.

At Mr. Goodrich's further suggestion, large-sized tension test bars were cut from $\frac{7}{8}$ in. plate. Dimensions between gage marks were $\frac{7}{8}$ in. thick (the original plate), $3\frac{1}{2}$ in. wide, and 18 in. long. Five heats of the above-mentioned steels were used ranging in carbon content from 0.29 to 0.38%. Average results for the three methods of preparation are as shown in the table at the top of the page.

The physical properties of the bars having

demonstrated beyond question that the flame softened edges have properties comparable to those produced by the most approved machining methods. For this reason flame softened cuts may be used successfully in the fabrication of high strength structural steels into tower members for suspension bridges, arch members for long spans, railroad vehicles and many types of heavy machinery. The method is also very useful in foundries for all clean-up cuts on alloy steel castings, and in steel mills handling high carbon and alloy steels.

Physical Constants of Pure Aluminum

By C. S. Taylor, L. A. Willey, Dana W. Smith and Junius D. Edwards

Aluminum Research Laboratories, New Kensington, Pa.

All measurements made on electrolytically refined aluminum of the following purity:

Chemical Analysis:

Silicon	0.0020
Iron	0.0001
Copper	0.0010
Sodium	0.0003
Calcium	0.0003
Magnesium	0.0003
Aluminum, by difference	99.9960

Mechanical Tests: [14-gage sheet, medium grain size]

	COLD ROLLED 75% REDUCTION	ANNEALED
Tensile strength, psi	16,300	6870
Yield strength, psi	15,430	1770
Elongation, %	5.5	48.8
Brinell hardness number	27	17

(12.61 kg. on 1/16 in. ball.)

Density: 2.6989 at 20° C.

Melting Point: 660.2₄° C.

Lattice Parameter: [face-centered cubic] 4.0413 ± 0.0001 Å at 25° C.

Thermal Expansivity: [20° to 500° C.]

$$L_t = L_o [1 + (23.22t + 0.00467t^2 + 0.0000078t^3)10^{-6}]$$

TEMPERATURE RANGE	AVERAGE LINEAR COEFFICIENTS
20° to 100° C.	23.86 x 10⁻⁶
20 to 200	24.58
20 to 300	25.45
20 to 400	26.49
20 to 500	27.68

Electrical Properties:

Volume resistivity in microhm-centimeters at 20° C.	2.6548
Volume per cent conductivity	64.94%
(International annealed copper standard = 100%)	
Mass resistivity in ohms (meter, gram) 20° C.	0.07165
Mass per cent conductivity	213.92%
(International annealed copper standard = 100%)	
20° C. constant mass temperature coefficient of resistance	0.00429

Radiation Characteristics:

Total reflectivity, light from tungsten filament [electrolytically brightened sheet]	90%
Emissivity at 100° F.	4.5%
[based on value of 5% for commercial foil]	

Two Contrasting Views About Troostite

Correspondence

BUFFALO, *N. Y.* — I have read over Doctor Sauveur's comments on the proper naming of the two types of carbide precipitates ("The Lamellar Family," METAL PROGRESS, May 1938) and would like to offer the following comments on the points at issue:

I would first like to say that I have a deep respect for Doctor Sauveur, his work and his opinions; I feel, however, that in this instance his remarks are augmented by a desire to retain the names of troostite and sorbite. I cannot say that I blame him for this for I likewise would like to retain in our metallographic nomenclature the names of those two distinguished savants Troost and Sorby. I believe, however, that troostite and sorbite as defined 25 years ago, are but stages or indications of the development of a stable precipitant and therefore, using Doctor Sauveur's words, "remind one of the little bear, the middle bear, and the big bear."

While I am aware of the fact that pearlite may be present in varying degrees of fineness in steel specimens, I feel that the fact that it is *lamellar* is the important factor to consider. Metallographically the fact that when iron carbide precipitates direct from austenite, it differs in shape from the form appearing when it is precipitated from martensite, is of vital importance and suitable names should be adopted to distinguish one from the other.

I personally am in favor of the adoption of two basic names for iron carbide precipitates, one for the product of the direct transformation from austenite which is plate-like and one for the transformation of martensite which is granular.

The continued use of the term "troostite" to identify the austenite → iron carbide + ferrite transformation and the use of the term "sorbite" to identify the martensite → iron carbide + ferrite phenomenon would in my opinion be a proper solution of this problem.

<div align="right">

B. L. McCARTHY
Chief Metallurgist
Wickwire Spencer Steel Co.

</div>

BERKELEY, *Calif.* — The question of the proper nomenclature for the microconstituents of steels has recently stimulated some very pertinent discussions. We agree with Professor Sauveur that in some respects the present inconsistent usage of nomenclature is unfortunate. On the other hand it demonstrates two vital points: In the first place, some metallurgists consider the definitions set forth by the International Committee on Nomenclature in 1912 to be inadequate and even misleading in view of the advances in technique and science during the intervening years. Secondly, metallurgy is not an antiquated science; it is vital and progressive and ready to abandon a good definition for a better and more useful one.

We, therefore, look with favor on the present turbulence in anticipation that it will eventually lead to the universal acceptance of a set of definitions more properly attuned to our present knowledge. In another 25 years or, if progress is more rapid in the future than it has been in the past, in a shorter period of time, we shall be very pleased to find that we have again advanced sufficiently to make our new definitions inadequate. Although unfortunate, the present condition is one to which American metallurgists may point with pride as indicative of the advances that have been made.

Professor Sauveur apparently favors the immediate action of a tribunal to quell the rebellion. On the other hand, Doctor Gillett, writing in the last issue of *Metals and Alloys*, prefers to "let nature take its course" before a

world court is allowed to offer its dogmatic definitions. The latter appears to be the least violent method of attack and we support it.

Nature *is* taking its course in many of the laboratories of this country. As an instance, in the Mechanical Engineering Department of the University of California we were recently confronted with the problem of arriving at a definite decision as to *our* definitions of the microconstituents of steels. Noting the inconsistencies in the literature and taking into consideration the pedagogy of our problem, we were forced to rely on our own ability to define the microconstituents. We found it necessary, however, to establish certain rules for selecting appropriate definitions:

1. The names should be simple.

2. The definitions should relate to what is seen with the microscope at a proper magnification and resolving power for the particular study in question, independent of what the composition, heat treatment, mechanical properties, phase diagram, or stability of the structure may be. If the above is inadequate, the X-ray structure should be given.

3. The definitions should be broad enough to be useful and precise enough to be unambiguous.

4. The definitions should be consistent with the recent advances in technique and in science.

5. They should not deviate greatly from those used in the best current literature.

Bearing these principles in mind, the definitions shown in the attached tabulation were tentatively established for the purpose of a rapid and accurate interchange of ideas between instructors and students. These definitions of ferrite, austenite, cementite, and carbide doubtless should require no discussion.

Pearlite, according to Rule 2, does not refer to a given composition, or to a particular heat treatment, or to any feature of the phase diagram. Any *stratified* mixture of ferrite and carbide, whether it be in plate-like lamellar form or a rosette-like stratification, is pearlite. This definition, we believe, fulfills Rule 3 by being sufficiently broad to be useful and sufficiently precise to be unambiguous. We have no objections, therefore, to any

legitimate adjective qualifying the term pearlite, with the meaning just stated.

The remaining microconstituents form a continuous series of patterns in the order listed with no definite line of demarcation. The light etching acicular needles, as commonly found in hardened steels, are called martensite. Alpha martensite may be distinguished from beta martensite by the X-ray structure. In troostite the needles etch darkly due to the precipitation of the carbide. Furthermore the body-centered cubic lattice is not supersaturated with respect to carbon. In sorbite the acicular structure is not present and a fine granular dispersion of carbide exists.

The term spheroidized, in our opinion, may apply to a steel of any composition and heat treatment that has a globular dispersion of carbide, independent of whether the previous structure was pearlitic, martensitic, troostitic, or sorbitic.

We believe the above definitions have certain virtues and fulfill our five qualifications fairly well. In many respects they are comparable to the definitions of the joint committee of A.S.T.M., S.A.E. and A.S.M. (⊕ Metals Handbook, 1936 Edition, page 210).

J. E. Dorn

Assistant Professor of Mechanical Engineering
University of California

Constituents of Steels

Microconstituent	X-ray Structure	Microscopic Structure
Ferrite	Iron or an alloy of iron forming a body-centered cubic lattice	Polyhedral grains
Austenite	Solid solution of carbon in the face-centered cubic lattice of iron or an alloy of iron	Polyhedral grains
Cementite	Iron carbide, Fe_3C, orthorhombic lattice	Dark etching with picr.. Exhibits numerous for.. dependent upon genesis
Carbide	Complicated lattices of any metallic carbide including cementite	Dark etching with picr.. Exhibits numerous for.. dependent upon genesis
Pearlite	Ferrite and carbide	Stratified mixture of dark etching carbide and light etching ferrite
Alpha martensite	Solid solution of carbon in a body-centered tetragonal lattice of iron or an alloy of iron	Light etching acicular needles
Beta martensite	Solid solution of carbon in a body-centered cubic lattice of iron or an alloy of iron	Light etching acicular needles
Troostite	Ferrite and carbide	Dark etching acicular needles
Sorbite	Ferrite and carbide	Dark etching fine granular dispersion of carbide in ferrite
Spheroidized cementite (carbide)	Ferrite and cementite (carbide)	Globular dispersion of coalesced carbide in a matrix of ferrite

Conductivity of Aluminum

TURIN, *Italy* — Numerous meetings have been held by Committee VII (on Aluminum) of the International Electrotechnical Commission during the last decade, and it has tentatively been decided that in international specifications the conductivity of aluminum wire will no longer be expressed in percentages of the conductivity of standard copper, but by its specific resistance, that is, the resistivity of a wire, 1 sq.mm. in cross section, 1 m. long, at 20° C.

Final decision should be reserved until proper consideration can be given to a very practical suggestion by Mr. Giovine — namely that an alternative method be authorized which gives an intuitive idea of the conductive properties of commercial aluminum. It is obvious that such a result would be obtained by following the lead of the copper industry, namely, expressing the conductivity in the specification as a percentage of the conductivity of a "technical standard," having optimum properties. The figure then would immediately give a clear idea of the quality of a conductor wire or cable.

Unfortunately in the practical application of this obvious and simple principle, serious difficulties are met in the determination of an "international aluminum sample." To avoid such difficulties (connected with the origin and the quality of standard aluminum, the processes of hot and cold working, the limits of precision in dimensions) Mr. Giovine suggests that "the electrical conductivity of aluminum be expressed as a percentage of the conductivity of an international conventional sample of technical aluminum."

This *conventional* sample should be defined as follows: "A reheated aluminum wire, 1 m. long, with a uniform section of 1 sq.mm., and having an electrical resistance of 1/36 of one ohm at the temperature of 20° C.

The choice of the fraction 1/36 is suggested for two reasons: First, because its form is similar to that already adopted for copper (1/58 of one ohm), and second, because the value 1/36 of one ohm corresponds exactly to the lowest resistivity of a r e h e a t e d w i r e (0.02777 ohm$\times$mm.$^2\div$m.) made with "commercial aluminum for electrical conductors," as usually produced in different countries.

The adoption of such a conventional sample has also the great advantage of eliminating the necessity of a definition of what has been called "the normal resistivity," and thus greatly simpli-fying the international specifications established by the Congress of November, 1937.

FEDERICO GIOLITTI
President, Societa Alluminis Veneto

A Note on Dynamic Equilibrium

PRIBRAM, *Czechoslovakia* — The phase rule, which is the basis of equilibrium diagrams used in metallurgy, assumes that the system is influenced by pressure and temperature. Metallurgists commonly assume that pressure has small influence; consequently alloy diagrams are drawn with temperature as the prime variable. *Equilibrium* is also assumed, although true equilibrium cannot be attained. Practically, therefore, *time* is an additional variable to be regarded.

It is well understood, for instance, that in the normal cooling of a binary alloy like steel, there is not time enough for the diffusion of carbon from the carbon-rich melt into the carbon-poor austenite first freezing out. The result is that the actual solidus line (line *JE* on the iron, iron carbide diagram in METAL PROGRESS, October 1937, page 342) is lower and to the left. The same is true of the transformation of austenite into alpha iron and iron carbide; the pearlite has a lower amount of iron carbide as the cooling has been the quicker.

However, it is not so well remembered that the opposite considerations operate on reheating. Pearlite cannot be changed into austenite instantly when A_1 is reached; furthermore it requires time or a higher temperature for the grains of ferrite to transform and to absorb cementite. If no diffusion of carbon occurs, the alpha iron could be changed into gamma iron only at the A_3 for pure iron (point *G* on the equilibrium diagram, or 1670° F.). If heating is quick and diffusion sluggish, the actual A_1 can be higher than the theoretical A_3 corresponding to the carbon content of the steel. The two alpha irons — the grains of excess iron and the plates in the pearlite — must change to gamma iron, the change in the pearlite actually being quicker because the plates enrich themselves in carbon by diffusion from the cementite close at hand. This lag on heating is, of course, the greater with coarse microstructure, with spheroidized cementite, or with stable and complex carbides containing, say, chromium and tungsten.

ALEXANDER MITINSKY
Professor
Pribram College of Mines

Interdendritic Pipe
in Steel Castings

PARIS, *France* — With the rapid developments in alloy steel castings, attention is being centered on the securing of good mechanical characteristics in the cast (not forged) condition. This will undoubtedly increase the uses of steel castings.

The strength of castings, however, often depends far less upon the specific properties of the metal of given analysis as exhibited in forged test pieces than upon the *compactness* of the metal in the cast state — that is, the absence of porosity or defects in continuity, often microscopic in nature. These defects are, in most

they occur at the intersection of convergent dendritic directions. Micrography, however, is not the best method of studying them, since the micrographic section, being made at random, does not necessarily pass through these small defects, and if it does, the cavities may often be filled in or concealed by the polishing operation. The fracture test, particularly at blue heat, is preferable to uncover them and, as shown in the macrograph at 8 diameters, will also indicate the relationship between the position and shape of these cavities and the dendrites.

Interdendritic pipes are formed either *(a)* during the second stage of solidification (see METAL PROGRESS, March 1934, p. 44) by the retreating flow of liquid through the entangled
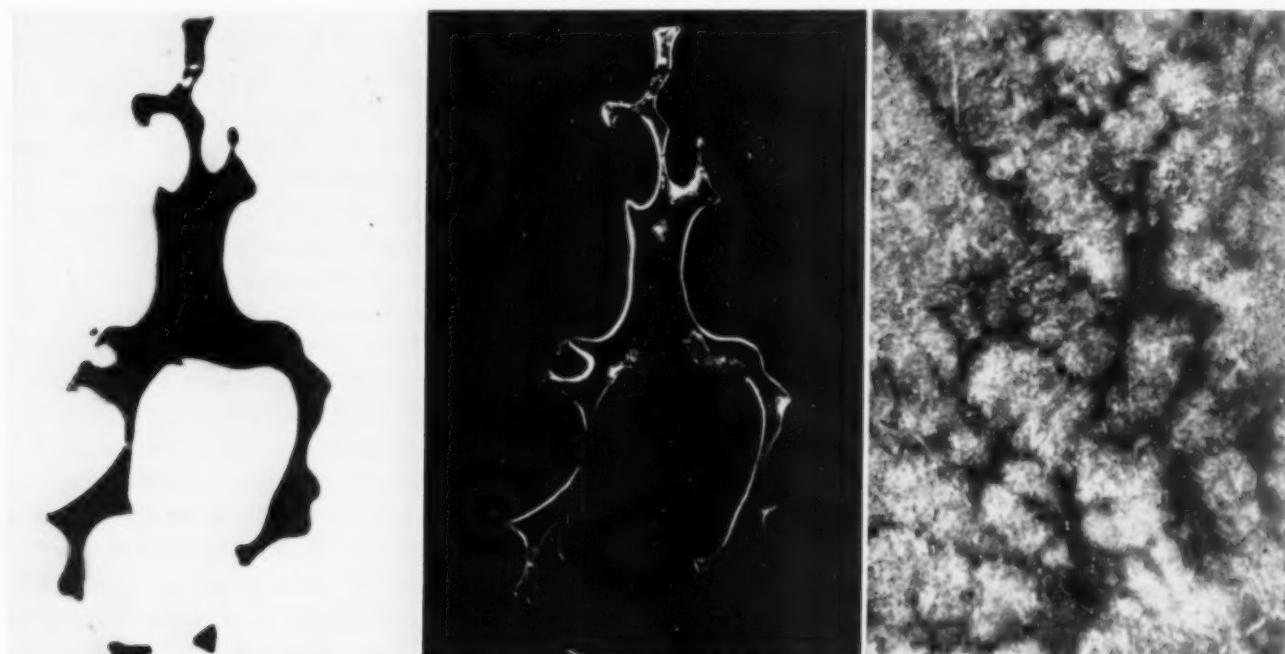
Three Views of an Interdendritic Pipe in a Steel Casting. Left and center not etched, × 300, direct and oblique illumination respectively. Right etched, × 150

cases, the origin of fracture in metal parts in service as well as in test pieces used for control.

Consequently the first condition that must be fulfilled by cast steel, in order to give satisfactory mechanical results under test, is to eliminate interdendritic pipe, also called "micropipe" by G. Charpy who, in 1920, was among the first to note its presence in steel ingots.

Micro-pipes are tiny cavities with dimensions often on the order of a fraction of a millimeter, with irregular and ragged outlines (a feature distinguishing them from microscopic blowholes), and with non-oxidized walls. Etching, especially with copper reagents, shows that

dendrites, locating them near the major pipe, or *(b)* during the third stage of solidification, by the contraction on freezing of the last portion of the liquid enclosed by surrounding partitions.

Thus, no micro-pipe is to be found in the oriented peripheral zone of castings and ingots in which basaltic crystallization progresses uniformly inward without encircling any remaining liquid. The defect is found, however, in the non-oriented central zone of crystals, where dendrites growing in various directions meet.

In principle, the presence of micro-pipes can be revealed by the determination of density (an index of compactness of metal) as is

*Dendritic Aspect of Fractured Test Piece,
Taken From a Steel Casting Containing
Numerous Micro-Pipes. Magnified 8 diameters*

done to determine porosity in welds, but precise measurement is necessary and the method is not very sensitive. The preferred method is the determination of tensile characteristics, for these small, sharp-angled cavities act as so many notches provoking cracking and breaking during plastic flow. The presence of micro-pipes, therefore, even invisible ones, considerably decreases the elongation and reduction of area of the tensile test pieces. This is clearly shown by the results at the bottom of the page.

These results show that by forging at a sufficiently high temperature and under sufficient pressure the walls of these small cavities are welded together with considerable improvement in properties. Sufficient working is necessary, however, for in the process of deformation the cavities may be open before being flattened out and closed.

A bend test also shows the effect of interdendritic pipe in the stretched regions. Toughness, determined by the notched bar impact test, is also affected by these tiny defects, although it is less sensitive to them, especially when they are few in number, since the notch in the test piece determines the path of fracture and this path may contain no pipe, whereas in the tensile test a comparatively large volume of metal "voluntarily" fractures on a path of rupture traced by these defects.

To avoid micro-pipe in castings, the foundry operations must be carefully controlled, such as feeding of the molds, chills, casting temperature, choice of metal, and even size and shape of the cast part if necessary. Cast test pieces from which tensile specimens are to be taken should be especially well designed as to shape, dimensions and cooling rate.

To obtain the desired mechanical characteristics in alloy steel castings, two other requirements are necessary in addition to the indispensable foundry requirement of compactness or absence of micro-pipe. They are: *(a)* Choice of a steel having hardenability adapted to the thickness of the part (a metallographic factor); and *(b)* sound metal to avoid intergranular fracture or slipping, sometimes requiring a preliminary homogenizing treatment.

If these requirements are met, it is possible to obtain for every type of alloy steel casting, after hardening and tempering at the proper temperature, a merit index (tensile strength in thousands psi. plus 3.5 times the elongation) of 170 or higher.

ALBERT M. PORTEVIN
Professor
Ecole Centrale des Arts et Manufactures

Tests From 8.7-In. Ingots, as Cast and as Forged 10% (G. Charpy)

LOCATION OF TEST PIECE	AS CAST			AFTER FORGING AND HOT WORK (REDUCTION OF 10% IN HEIGHT)		
	TENSILE STRENGTH	ELONGATION	REDUCTION OF AREA	TENSILE STRENGTH	ELONGATION	REDUCTION OF AREA
Along axis of the ingot	43,500 psi.	0%	1.5%	96,000 psi.	8%	11.4%
2.3 in. from the axis	97,500 psi.	8%	12.7%	101,000 psi.	16%	20.6%
3.5 in. from the axis and 0.8 in. from the surface	100,000 psi.	18%	26.9%	99,000 psi.	20%	28.2%

Personals

Benjamin A. Weed ⊕ has been transferred from the Atha mill of the Crucible Steel Co. of America to the New Haven branch.

Orin B. Jacobson ⊕ has left the Carnegie-Illinois Steel Co. and is now employed as technical adviser by the Revere Copper and Brass Co., Chicago.

Appointed head of the department of metallurgical engineering, Case School of Applied Science: Kenneth H. Donaldson ⊕, taking over the duties of Herbert M. Boylston ⊕, granted leave of absence due to ill health.

Appointed technical engineer by Steel Founders' Society of America: C. W. Briggs ⊕, formerly physical metallurgist in the Naval Research Laboratory, Washington.

Harold L. Walker ⊕, assistant professor of metallurgy, School of Mines and Geology, State College of Washington, Pullman, Wash., has accepted an appointment as assistant professor of metallurgical engineering at the University of Illinois.

John C. Bancroft ⊕, formerly employed at Cuyahoga Works, American Steel & Wire Co., is now employed in the metallurgical department of the Perfect Circle Co., New Castle, Ind.

E. J. P. Fisher ⊕ has been made assistant manager, tube mill and cold drawing division, Aetna-Standard Engineering Co., Youngstown, Ohio.

W. E. Ruder ⊕, metallurgical engineer for the General Electric Co., is to be on the directorate of the new merger to be known as the Allegheny Ludlum Steel Corp.

John R. Freeman, Jr. ⊕ has been appointed technical manager of the American Brass Co.

Willis T. Cramer ⊕, formerly works metallurgist at Cuyahoga Works, American Steel & Wire Co., has become assistant district metallurgist. Herbert H. Schneider ⊕ has been promoted to works metallurgist.

Appointed metallurgist of the Los Angeles plant, Bethlehem Steel Co.: Benjamin H. Brown ⊕, succeeding G. C. Stetter ⊕, appointed metallurgical engineer in charge of eastern products.

Charles Lee Clayton ⊕ is taking a training course with Columbia Steel Co., Pittsburg, Calif.

Transferred from Ft. Wayne Works, International Harvester Co. to new motor plant in Indianapolis: Prescott B. Jensen ⊕, as chief metallurgist.

Perry D. Gasnier ⊕ is now doing sales engineering work with Cincinnati Milling Machine and Cincinnati Grinders, Inc.
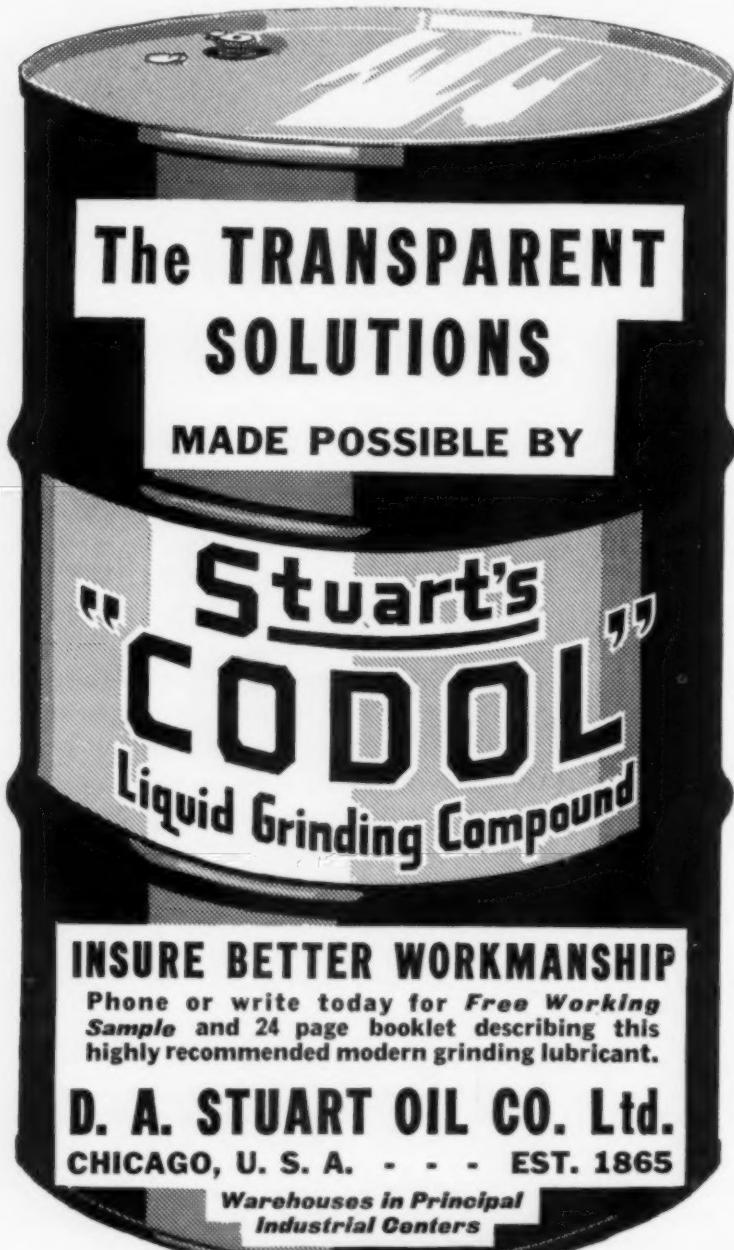
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Stainless Steels

(Continued from p. 139) and several beads of deposited metal required, the metal adjacent to the weld proper will be subjected to heating within the zone of dangerous temperatures for a longer time than would be the case in relatively thin plates or sheets. To illustrate this two views are shown on page 139. We see in them that an alloy of 25% chromium, 20% nickel, in the form of a $\frac{1}{4}$-in. plate, remained practically unaffected after welding and testing for corrosion, and is well suited for service under corrosive conditions that would not affect the base metal away from the welding zone. However, the same alloy in the form of $\frac{7}{8}$-in. plate has been slightly attacked upon corrosion testing in the areas adjacent to the weld.

To sum up, the following recommendations are offered:

A. **No welding is employed**

1. If the installations are intended for service within the temperature zone of 800 to 1500° F., or if in the course of service the installation may be slowly cooled through this range, material with either titanium or columbium should be used.

2. If the installations are intended for service at room temperature or below 800° F., either straight chromium-nickel or modified alloys should be considered.

B. **Welding is employed**

1. If the thickness of the welded metal does not exceed approximately $\frac{1}{2}$ in., no cross welding is done, and the assembly is to be used at temperatures up to 800° F., either straight chromium-nickel alloy or the alloy with titanium can be used. The choice of the metal is governed by the circumstances peculiar to the installation under consideration.

2. The use of chromium-nickel austenitic alloy with columbium is recommended when *(a)* heavy cross sections, greater than $\frac{1}{2}$ in. thick, are used in the construction, *(b)* multiple or cross welding is to be done, *(c)* the installation is to be operated within the temperature zone of carbide precipitation in the presence of corrosive media, *(d)* when stress relief of heavy cross sections after fabrication is necessary, yet the possibility of rapid cooling is precluded.

Here, too, BRISTOL'S PYROMASTER *is*

CONTROLLING FURNACE TEMPERATURES ACCURATELY

although shop vibrations are TERRIFIC

"no adjustment of any kind"

"as accurate as the day it was installed"

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SUCCESSORS TO
NEW ENGLAND ANNEALING & TOOL CO.

DROP FORGINGS · HEAT TREATING
MACHINING · GRINDING
SAND BLASTING

May 24, 1938

The Bristol Company
250 Stuart Street
Boston, Massachusetts

Gentlemen:

A year ago to this date we put in operation one of your "Pyromaster" Controller Recorder instruments working inconjunction with a Despatch Air Draw furnace with temperature ranges from 500° to 1250° F.

This "Pyromaster" has been functioning during some part or all of every work day, and for several months during the night for the past year without an adjustment of any kind. Regular monthly tests have shown it to be as accurate as the day it was installed.

These facts, as stated above, would not seem unusual under ordinary conditions, but as the whole installation is within nine feet of a 2000# board drop hammer and as the furnace foundation is within two inches of the concrete hammer underplacement it can easily be seen that any temperature controlling mechanism does certainly take terrific abuse. Two other hammers also contribute to the shock and vibration to which the "Pyromaster" is subjected, they being approximately twenty-five and thirty-five feet away.

We volunteer this information, not only due to our own satisfaction, but that you may not be hesitant in recommending or placing a "Pyromaster" installation in a like situation or in any other place where the apparatus might be subjected to trying and abusive conditions.

Yours very truly,

PORTER FORGE & FURNACE INC.

By R.G.Sault, V. Pres.

RGS:M

Conditions such as those in the Porter plant are unusually severe. However, since Bristol's Pyromaster has repeatedly demonstrated it is absolutely accurate and dependable in such severe service, you have ample assurance it will be equally reliable under any other conditions.

For recording and automatically controlling temperatures in furnaces, ovens, kilns, and heat treating processes. Write for Bulletin 507H.

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THESE BRISTOL'S PYROMETERS, TOO

WIDE STRIP POTENTIOMETER. Record is made on 12¼ inch wide strip chart. Catalog 1451H. *INDICATING PYROMETER CONTROLLER.* Compact, sturdy shop instrument. Bulletin 488H. *MILLIVOLTMETER PYROMETERS.* A complete line to choose from. Bulletin 488H. *RADIATION PYROMETERS.* For temperatures up to 3300°F. Bulletin 155H.

View at right shows Bristol's Pyromaster Potentiometer Pyrometer in the plant of the Porter Forge and Furnace, Inc., Everett, Mass. Although located only a few feet from three hard-working hammers, this Pyromaster has given accurate furnace temperature control ever since it was installed, over a year ago!

August, 1938; Page 163

Notes about contributors

Famed nearly as much for the personality behind his presentation of technical papers as for their technical quality is **Vsevolod N. Krivobok.** Russian born and educated, he was early commissioned by the Russian Government as a junior member of the Artillery Commission sent to America in 1915. Five years later he entered Harvard for graduate work and in 1924 joined the staff of Carnegie Institute of Technology. He now divides his time between that institution as professor of metallurgy and Allegheny Steel Co. as associate director of research. Typical of his contributions to the field of stainless and corrosion resisting steels is the paper for last spring's Western Metal Congress, currently being reproduced in **Metal Progress,** page 135. He presented the Campbell Memorial Lecture before the 1934 convention of the American Society for Metals, and is much in demand for talks before the Chapters.

⊕ ⊕ ⊕

Klaus L. Hansen, author of the leading article in this issue, came to the United States from Norway in 1901 with a bent for electrical machinery and an inquiring and inventive mind. His first five years here were spent in various electrical shops in Chicago and attending University of Illinois, then with Westinghouse in East Pittsburgh for the next thirteen years as tracer, draftsman, dynamo tester and designing engineer. Eventually he got into consulting and development work of his own. Arc welding generators were one of the problems that soon attracted his attention, with the result that he invented and designed the Hansen arc

welder, now manufactured by the Harnischfeger Corp. in Milwaukee, Wis., for which Mr. Hansen now acts as consultant.

⊕ ⊕ ⊕

Edward W. P. Smith was graduated as an electrical engineer from Colorado College, and got his early training before the War in the operation of a power plant in the West. Subsequent connections with various eastern firms culminated in successive positions for Lincoln Electric Co. as tester, electrical engineer and chief engineer. Then for a number of years he engaged in private consultation practice on the design and welded fabrication of machinery, oil field equipment and buildings. He is now consulting engineer for Lincoln Electric Co., with a background that well fits him to write on economics of welding, page 131.

⊕ ⊕ ⊕

The process of flame softening described on page 140 owes much of its development to the work of **Herbert H. Moss,** an engineer with Linde Air Products Co. Mr. Moss has also been instrumental in solving many other problems in the use of oxyacetylene welding and cutting in structural work. In 1931 he was called upon by President Hoover's Committee on Technological Developments to investigate the use of welding in small house construction. In 1932 Mr. Moss was awarded the Samuel Wylie Miller Medal of the American Welding Society. At this time he was engaged principally in extensive development work in connection with flame machining.

| Herbert H. Moss | Vsevolod N. Krivobok | Klaus L. Hansen | Edward W. P. Smith |

What a user found out about
LINCOLN *"SHIELD-ARC 85"* ELECTRODE

Tests made by Wellman Engineering Co., Cleveland, Ohio.

Analysis of steel welded: Carbon .20%—Molybdenum .68%—Manganese 1.26%

Electrode used: Lincoln *"Shield-Arc 85."* For welding all high-tensile low-alloy steels (up to approx. 90,000 lbs./sq. in. tensile) such as: medium manganese . . . manganese vanadium . . . manganese copper . . . chromium copper . . . chromium manganese silicon . . . nickel copper molybdenum . . . carbon ½ molybdenum.

RESULTS:

	AS WELDED	STRESS RELIEVED AT 1200° F.
Yield Point lbs./sq. in. (weld)	78,000	60,000
Ultimate tensile strength lbs./sq. in. (weld)	94,700	74,700
Bend elongation (weld) (Stretch of outside fibres)	62%	106% (Specimen illustrated)

We are pleased to show you the results of tests made by users of *"Shield-Arc 85,"* "Fleetweld" and other Lincoln Electrodes because invariably these findings surpass our claims. Try these new Lincoln Electrodes and see how they improve your products and cut your costs. Consult the nearest Lincoln office or mail the coupon.

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Metals in Marine Engines

(Continued from page 120) the blades strike water, for which condition we have as yet no remedy.

Oil engines are next to turbines on the basis of weight per shaft horsepower. They have their peculiar troubles. At any meeting of engineers dealing with oil engines it will be found that liner and piston ring wear cannot be kept long out of the discussion.

In the four-stroke single-acting engine the liner is a simple proposition, the pearlitic cast iron of which it is made will last for, say, 50,000 hr., or ten years. Some two-stroke and some double-acting engines have liners of comparatively complicated construction, and the cast iron for such is now alloyed with, for example, nickel, chromium, molybdenum, or vanadium and titanium; they cost about six times as much as liners of single-acting engines and last less than half the time!

We cannot sit down contentedly with that state of affairs. Is the remedy going to be the adoption of harder liners, or the electroplating of liners, or must the ship-owner continue to pay for the lighter oils supposedly required for the simpler engines? And should the piston ring be softer or harder than the liner, or of the same metal and characteristics?

Although much has been written about the wear of cylinder liners and piston rings in the internal combustion engine, no solution has yet been reached which finds general acceptance. Probably the correct solution of the problem is to make these of the same material, and as hard as possible so long as the hardness is due to the closeness of texture of the material, and to make sure of effective lubrication of the upper part of the cylinder liner.

It is also suggested that the question of piston rings is not finally decided.

Boilers — Present-day boilers are equally or more developed than the turbines which they supply. At one time a boiler was a kettle in which water was boiled. Now it has become a machine for the rapid production of steam.

The question still remains as to why our oldest friend, the tank or Scotch boiler, should have such a high factor of safety that its weight becomes a severe penalty. Consider, for example, the boiler shell. This is formed by bending the plate beyond the elastic limit, and it is not subsequently annealed.

Metals in Marine Engines

(Starts on page 120) It is obvious that the thinner the plate the less the internal stresses set up in the plate. The allowance of an additional thickness for wastage is unnecessary, as the thickness is 15% more than is required, the strength of the seam being only 85% of the strength of the full plate.

Metallurgical Advances — Looking backwards, it appears that the advance which has been made since the inventions of the steam engine, the steam turbine, and the oil engine, has been bound up very closely with the advance in workmanship (including, of course, accurate machining) and with metallurgy, and it is probably on the future progress of metallurgy that the rate of development will depend. We are still in need of cheap, standardized material capable of withstanding high pressures and temperatures, and resistant to such evils as creep, brittleness, and corrosion. That there is much to be learned is evident. Physicians do not know the cause and cure of the common cold. In the same way metallurgists cannot tell us why common wrought iron resists the ravages of time so much better than steel.

Cast iron has traveled on through pearlitic cast iron to be alloyed with chromium, copper, vanadium, titanium, molybdenum, and nickel. Are we on the eve of something definitely so superior to our past practice that we can standardize it?

Steel has been similarly alloyed and has been heat treated in a variety of ways. Will there be a simplification of these processes? In the eyes of marine engineers, brass, in the form of condenser tube, is one of the outstanding triumphs of metallurgy since the discovery of aluminum brass, 76 Cu, 22 Zn, 2Al. What is now wanted is the similar discovery and development of a metal to stand up to the temperature of burning oil, say, a modest 1500° C. (It sounds more reasonable in centigrade!). And an oil that will lubricate at that temperature. And nuts and bolts that will not be at or above their annealing point under these conditions.

If we are ever inclined to think that we have arrived and that there is no more to be done, it is a good thing to make out a brief balance sheet, putting on one side the things we know and on the other side the things we don't know. It should have an invigorating effect. This paper is intended in some small way to fill such a want.

METAL PROGRESS

Metal Progress

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AMERICAN SOCIETY for METALS

Metal Progress; Page 212

High speed trains & metallurgical research

Editorial

Just after the Editor returned from the Western Metal Congress last spring, an announcement reached his desk that the Zephyr fleet of trains operated by the Chicago, Burlington and Quincy railroad had passed the 5,000,000-mile mark in regular service. It probably is six million by now — and the Burlington is just one of several roads which are operating trains on really fast schedules.

One has only to travel west of Chicago to realize that high speed passenger transportation has become the ideal of Western railroad executives — men who as a class have frequently been criticized as most careful and conservative in their business attitudes. Chicago to Minneapolis at a mile a minute; Chicago to Denver at 68 miles an hour (including ten stops); Chicago to Los Angeles or San Francisco in 40 hr. — these are marvelous performances, even as the result of a century's railroad development. These luxurious trains float along at bursts of speed so high that nervous back seat drivers would pull an emergency cord if a speedometer were visible.

These fundamental changes in the railway industry are due in large part to a common-sense application of technical ideas well developed by its competitors, air and motor transport, rather than intensive original research by the railroads themselves. Elimination of surplus moving weight by refined design in stronger steels, light metals or non-metallics; streamlining to reduce wind resistance; improvement of steam power plant or substitution of perfected diesel engines; modernization of the spring suspensions and shock absorbers; air conditioning of coaches and diners — this combination has made today's train as much beyond the passenger train of yesterday as the train of yesterday was ahead of the stage coach and canal boat.

In all these things advanced metallurgy has had a part, and it is impossible to measure the full extent of their influence. That is almost a truism; one is reminded of a remark made by Robert Leach, vice-president of Handy & Harman, when escorting a visitor through his model plant devoted to silver and its alloys: "Twenty-three years ago, when this plant was built, the silver solders were almost insignificant; during several months in 1937, however, their sales value indicated that they were one of our major products." One might add that they have become an industrial necessity, whereas sterling silver remains a luxury to most Americans.

It is a far-sighted executive who can forecast the ultimate value of a new development, even approximately. Here, probably, is the greatest criticism of the railroad men — they did not start their improvements until the competitive situation was desperate. A precisely opposite attitude has reaped rich rewards in at least one branch of the metal industry:

Fifteen years ago the developing art of die casting promised great manufacturing economies for makers of small machinery. Various zinc alloys of that day, however, while easy and cheap to cast, proved unreliable in some services — for instance, they would swell, lose strength, and even crumble in moist locations. Researchers at New Jersey Zinc Co.'s laboratory discovered that common impurities in the ordinary zinc must be eliminated practically completely in order to stabilize these alloys. While zinc 99.95% pure had been available for many years, and one might think that that was about the commercial limit, it did not prove to be good enough for die castings as we know them today.

Be it remembered that an extensive demand for zinc die castings, on account of their bad reputation, was at that time purely hypothetical. That, however, did not interrupt the vigorous work on them. It was a time-consuming investigation, for the troubles that were to be corrected could often be measured only after years of exposure in damaging atmospheres. However, successful application of zinc, 99.99% pure, in improved alloy analyses, has so corrected the situation that the present consumption of zinc in die castings, far from being the inconsiderable figure of 5000 tons a year, now in America alone is approximately 100,000 tons per year!

These two instances — silver solders and zinc die castings — are only two from many that the railroad men might remember when they begin to doubt whether improved passenger schedules are worth what they cost. The metal industry is full of examples where the price of survival has been continual research and revolutionary improvements in operating methods.

By L. C. Conradi
Technical Research Director
International Business Machines Corp.
Endicott, N. Y.

Heat treatment by high frequency induction

USE OF HIGH FREQUENCY induction heating for the heat treatment of steel now offers the metallurgist and manufacturer a new and distinctly improved method of selective heating for purposes of hardening and annealing. Whereas the application of this type of heating to large parts such as automobile crankshafts is now approximately two years old, and its use on continuous strip such as razor blade steel even older, the commercial application of induction heating to comparatively small machined parts such as are used in electric bookkeeping and accounting equipment is still in its infancy.

Even so, several months of practical experience with induction heating in this field of application already indicate that this method will in a large measure modify and replace the present practice of selective hardening and annealing. As compared with the present well-known methods of selective hardening such as torch heating, localized heating in a lead bath or a salt bath, and selective carburizing using copper plate or a clay mixture as a protective coating, induction heating has the advantage of greater flexibility, speed, economy and accuracy.

Equipment required for the induction heating of comparatively small parts, as mentioned before and as illustrated on the opposite page, consists of a so-called converter for producing high frequencies (heating applications use in excess of 20,000 cycles per sec. up to perhaps 500,000 cycles per sec.) and coils of water-cooled copper tube, such coils conforming roughly to the size and shape of parts to be heated. As compared with other available types of high frequency generators the "quenched spark gap" type of converter has the advantage of low initial cost and low maintenance cost.

Enough has been written about the coreless induction furnace to make superfluous any long account of how the high frequencies are generated and how the heating by induction is accomplished. In our set the line voltage of 60-cycle current at 220 volts is stepped up to 2000 volts in an ordinary transformer. The high voltage side of this transformer is connected to the two ends of the heating coils. In both these connecting lines, however, is a bank of condensers, and across the circuit, between these and the heating coil is a third bank of condensers. Between condensers and transformer a spark gap is also connected across the circuit.

In operation the line voltage charges the condensers to a potential sufficient for a current to jump across the spark gap. The gap then momentarily becomes a conductor and remains so until the condenser has given up all of its charge. The moment this occurs the gap acts as an open circuit and the condenser again can be charged. This sequence of actions is repeated continuously. The property which the gap possesses of returning to its un-ionized or non-conducting state is called "quenching" and therefore the term "quenched spark gap" is used to describe this particular arrangement.

The metal part to be heated is held inside the coil of copper tubes, which is now carrying

oscillating or interrupted current at high frequencies, and is heated by the electric currents induced into it. There is no metallic contact between the part and the coil. The coil generates an electric field, concentrated within it along the axis, w h i c h is oscillating 200,000 times per sec., and the metal part intercepts this electric field and eddy currents are established inside this metal part. This induced current then generates an equivalent amount of heat. The action may be compared with a transformer in that the heating coil corresponds to the primary winding and the metal part to be heated corresponds to the secondary winding.

Now suppose that t h e equipment is ready and a panful of parts is ready for treatment. By experimenting with several pieces, the operator easily determines the correct setting for the power control (knob at lower left side of cabinet) and the correct tuning of the high frequency output (knob in upper center). Judging the temperature by eye and by visual examination of the fractures of hardened parts, checking the hardness by file test and Rockwell C readings, he can readily determine the correct practice. Settings of the tuning dial and power control dial, time, and the heating coil number are recorded for each part for reference at some future time.

The operator need only exercise reasonable care in centering the part within the coil in order to obtain uniform heating.

Hardened gears and cams almost without exception require hardness only in the teeth and the cam surface and at the same time require a soft hub and hole to permit subsequent drilling for taper pinning, during assembly operations. Before the introduction of high frequency induction heating it was necessary to copper plate a gear blank or cam blank prior to machining. This copper would be removed from the teeth or cam surface by the machining

Complete Equipment to Utilize 8-Kw. Power for Heating Small Parts by High Frequency (200,000 Cycle) Induction. Inset shows bevel gear being heated in conforming coil

operations, and the regular carburizing and heat treatment would harden these surfaces only, leaving the hub and hole soft where the copper plate remained.

In some cases it was more advantageous to pack the hub and hole of a gear or cam with a moist clay mixture and allow it to dry and bake over night before proceeding with the carburizing and heat treating operation. The clay mixture, like the copper plate mentioned above, served to prevent carbon penetration and consequent hardening of the hub and hole section.

With this old method in use heretofore on gears, cams, shafts and arms, it was necessary to reheat the section to be hardened in molten lead at a temperature of 1400 to 1450° F. which, no matter how carefully done, always carried out a generous amount of lead adhering to the
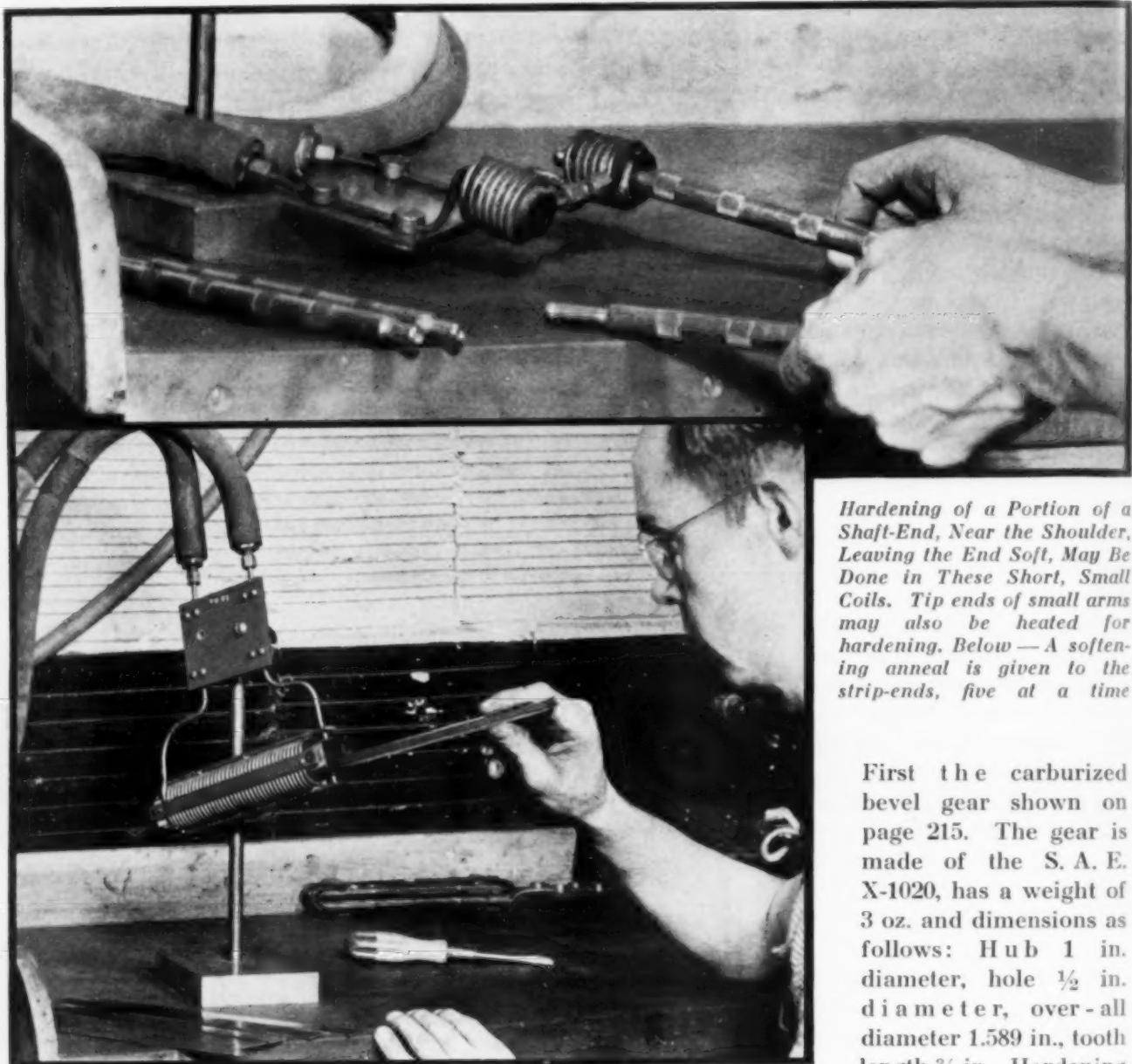
Hardening of a Portion of a Shaft-End, Near the Shoulder, Leaving the End Soft, May Be Done in These Short, Small Coils. Tip ends of small arms may also be heated for hardening. Below — A softening anneal is given to the strip-ends, five at a time

First the carburized bevel gear shown on page 215. The gear is made of the S. A. E. X-1020, has a weight of 3 oz. and dimensions as follows: H u b 1 in. diameter, hole ½ in. d i a m e t e r, over - all diameter 1.589 in., tooth length ⅜ in. Hardening requires approximately

parts. Removing this lead from the parts always required an extra operation — either scraping by hand or wire brushing. So, briefly stated, copper plating, claying of hub and hole, and removing adhering lead have been largely eliminated by high frequency induction heat treatment.

Induction heating offers an additional advantage that it will be possible to use 0.40 to 0.50 carbon steels and alloy steels for many gears and cams instead of a low carbon carburizing grade, and thus eliminate the carburizing operation which would otherwise be a necessary requirement for selective hardening. In all instances there is a minimum of scale and distortion with induction heating.

Some specific instances will now be quoted.

18 sec. with a power input of 6 kw. The temper is drawn in the usual manner at 350 to 450° F.

The shaft shown at top of this page is made of S.A.E. X-1112 cold-drawn steel and is carburized 0.015 to 0.020 in. deep. Induction heating permits us to harden the 0.338-in. bearing end to Rockwell C-62 minimum for a length ¾ in. out from the shoulder, leaving approximately ⅜ in. of the extreme outer end soft for subsequent machining operations. The same coils are suitable for such things as a reset arm, made from 0.078-in. thick S.A.E. 3115 cold-rolled strip. After carburizing, the ends only are heated by induction and hardened to Rockwell C-62 minimum, using a power input of 4 kw. for 5 sec.

Overthrow lock bars, as shown at the top

Coils Do Not Need to Be Round — Witness the Above for Hardening the Prongs of a 1020 Bar. Fixtures can be used when heating several very small parts simultaneously, even heating them selectively, so that one end of the part remains soft

of this page, are made of 0.312x1.125-in. S.A.E. 1020 steel and are carburized 0.015 to 0.020 in. deep. In order to meet s e r v i c e requirements and keep distortion and dimensional change to a minimum, the prongs only are hardened to at least Rockwell C-62 for a distance of 0.28 in. b a c k from the end. Induction heating easily meets all these requirements in approximately 35 sec. with a power input of 6 kw.

The type bar as shown in the lower view on page 216 is blanked from 0.050 in. thick S. A. E. 1010 cold-rolled steel having a Rockwell hardness of B-90 to 105. The wide end is annealed by induction heating to Rockwell B-50 to 60 in order to bend the edges at right angles to form the type case. Using a power input of 5 kw., five bars can be annealed in 35 sec.

The gear studs shown in the final view must have a hardness equivalent to Rockwell C-62 minimum all over except for the tenon end which must be left soft so it can be riveted over during assembly operations. Using a holding fixture made of transite, seven parts can be heated to the proper hardening temperature at one time with a power input of 4 kw. In an hour 500 to 600 pieces can easily be treated in this manner. In addition to its function as a mounting plate, the transite serves as an insulator for the tenon ends, thus preventing heating and hardening of the same.

The foregoing illustrations indicate the wide field of application induction heating is certain to have in modern heat treating practice. While the examples cited may be classed as batch and hand type operations, heat treatment by induction heating readily lends itself to fully automatic and continuous operations by designing and using suitable conveyor feed for parts on which production is large enough to warrant such an installation.

By Edward G. Mahin
Professor of Metallurgy
University of Notre Dame
Notre Dame, Ind.

Distinctions between pearlite, troostite and sorbite

AT LONG LAST I have decided to "write a letter to the Editor", a thing which I have, at various times in my life, itched to do but which — until the present moment — I have never done. In this particular instance I am prompted by the desire to add my bit to the perennial discussion concerning the nomenclature of microconstituents of the iron-carbon alloys. This discussion waxes and wanes, in volume and feeling. Sometimes the subject will remain in a state of innocuous desuetude for months or years — and again it will attain temperatures commonly designated as fever heat. The high temperature stage was approached, for example, in the excitement following the publication of the paper by Vilella, Guellich and Bain, "On Naming the Aggregate Constituents in Steel" in METAL PROGRESS in August, 1935. Again, interest has lately been aroused by the publication of Dr. Sauveur's highly entertaining "The Lamellar Family" as the leading article in the May issue of METAL PROGRESS and of his more serious and less ironical "Wanted: An International Committee on Nomenclature" (*Metals and Alloys*, Vol. 9, page 137, 1938).

I frankly confess that, although I do not feel as apprehensive about the matter as Dr. Sauveur appears to feel, I do strongly sympathize with his general views. Realizing that language is, in the last analysis, a means for communicating ideas and feelings and opinions, and that words and terms and p h r a s e s a r e invented to express such things, later to be modified a c c o r d i n g to widened information and diversified usage, I still hold (with Dr. Sauveur and everyone else, I think) that it is a matter of importance to have such words and phrases as nearly definite in meaning as possible so that each of us shall understand, so far as may be, just what the other is talking about when he employs these vital tools in spoken or written discourse.

With all due respect to Messrs. Vilella, Guellich and Bain, the authors of the first paper above cited, and to their considered opinions, I do not favor widening the use of the term "pearlite" to include what we have been designating as "troostite" and "sorbite". It is true (or at least we so believe) that troostite and s o r b i t e — also apparently martensite — are microstructures composed of ferrite and cementite, the same phases as are in pearlite. But it does not seem to me that it logically follows that we must therefore abandon these formerly accepted terms as designating certain recognizable microstructures, developed through rapid cooling and possessing quite different mechanical properties and micro-appearance, merely because they are made from the same building units.

I do not base this opinion upon the elemental fact that Henry Marion Howe invented the term "pearlyte" because of the pearly appearance of polished and etched annealed steel. Names are constantly being broadened and changed in meaning, until sometimes they almost entirely lose their original significance as related to physical appearance, assumed chemi-

cal properties, or etymological derivation. In particular cases we may have mental reservations as to the wisdom or the utility of such methods of word evolution, but we cannot change matters very much by uttering polemics against them.

Derivation of the Names

As a single example, consider our term "cementite", designating the phase fundamentally consisting of iron carbide but containing also, in solid solution, any other element present, or carbide or compound present or capable of being formed, up to the limits of their solid solubilities in the iron carbide. So far as its etymology is concerned, the word cement starts with the Latin *caedera*, to cut, hence *caedimentum* and its contraction *caementum*, which settled into "a rough, unhewn stone from which mortar was made" (Webster). How the word "cement" came to be applied to the bony tissue forming the outer crust of a tooth, and the word "cementation" to mean the process whereby a crust of hard steel could be produced on a bar of soft wrought iron, is not shown in the available dictionaries. At any rate the outer rim of blister steel, the product of cementation, was rich in a certain microconstituent which turned out to be iron carbide and what would be more natural than to call it "cementite", the hard constituent in cemented iron?

It was first described by Sorby as the "intensely hard constituent" and one may assume an additional reason for the term, as applied to our own iron-carbon p h a s e — because of its hardness it is similar to the wearing surface of a tooth, or something hard enough to cut (*caedera*).

As a matter of fact what metallurgist ever bothers his head about such matters, or who ever will, other than a lexicographer? We continue to use the name because it has a fairly well-defined significance to us, hence is quite satisfactory for the purpose.

To the casual metallurgist "cementite" means the compound represented by the chemical formula Fe_3C. To the somewhat more thorough and discriminating student of metallurgy it signifies a *phase*, defined more or less as above. Sometimes it is far from being pure iron carbide, as in alloy steels containing carbide forming elements, yet we experience no special embarrassment in the use of the term. Whether one is inclined to be meticulous or careless in the selection of words and terms, usually everyone understands what we are talking about when we speak of cementite in discussing any given type of iron-carbon alloy.

My personal objection to the extension of the term "pearlite" to include what we have been accustomed to designate as "troostite" or "sorbite" is not based upon any romance connected with its origin (as some of the comment would seem to imply) but upon my feeling that by so doing we not only fail to simplify the connotations of our accepted terminology — we actually cloud and render them more vague. The microstructure whose nature was revealed by Sorby's work was a normal transformation product of saturated or eutectic austenite, formed upon slow cooling of the alloy, and "pearlite" has meant that very thing to metallurgists through these many years. (Note that I prefer "eutectic" to "eutectoid", but of that, more later.) It is granted that "eutectic austenite" varies in carbon content, since other elements may be present in appreciable proportions. So does ferrite, yet we retain this name for the phase. A nickel steel forms eutectic austenite (and later pearlite) having less carbon than is found in the eutectic of a simple steel. But ferrite, in such a steel, also is different in composition, containing nearly all of the nickel in addition to the saturation content of carbon, the last in turn being altered by the presence of nickel. Yet we still call it "ferrite". Unlike elements or compounds, *phases* are not constant in composition. This being true, eutectoid mixtures of phases may vary in composition without losing their special identity as phase mixtures derived from transformation of eutectic solutions.

Certain comment, leading to the inference that the term "pearlite" has no very definite significance merely because the relative amounts of its constituent phases vary according to elementary composition and cooling rate of the alloy, appears to me to be without much point. The matter of variation in alloy composition has been discussed above. This brings us to the consideration of troostite and sorbite.

Just as "pearlite" has been given a meaning, as nearly definite as possible considering variable alloy composition and cooling rates, so "troostite" and "sorbite" have been names for fairly distinct and recognizable microstructures, obtained through *rapid* cooling of iron-carbon alloys, under conditions such that equilibrium could not even be considered as

being approached, much less being attained.

Just where, in the consideration of cooling rates, cooling should be called "rapid" and where "slow" is a matter not so easy to decide. The same statement may be made regarding "equilibrium". To paraphrase rather liberally a purported observation of Mark Twain concerning the weather, equilibrium is something which lots of people talk about but which nobody has. Strictly speaking, we may consider an alloy system (or any other physical system) to be in equilibrium only with infinitely slow cooling or heating. Actually we approach this condition closely enough, in many cases, so that we are entitled to speak as though we had attained it — thus "equilibrium diagrams", which nobody ever has established nor ever will.

Consequently "pearlite" may not ever be quite the ideal eutectoid mixture of ideal ferrite (pure alpha iron) and ideal cementite (pure iron carbide). From every practical viewpoint, nobody expects it to be so and, again from the practical viewpoint, the question is purely academic. When heat treating steel we either cool quite slowly, as in the furnace, or we quench in some manner, as in air, oil, water, or some other medium. In the first case we intentionally provide opportunity for approximate equilibrium to be established, hence we find "pearlite" along with primary ferrite or cementite in the structure. In the second case we intentionally hurry the cooling, thus producing some other desired microstructure with modified mechanical properties and hence we find "martensite", "troostite" or "sorbite", or perhaps some other approximately designated microstructure, to be suggested by metallurgists of the future.

Suppose that martensite, troostite, sorbite and pearlite *are* all composed of the same two phases, ferrite and cementite. To call them all "pearlite" (fine, coarse, lamellar or globular) because of this is no more logical than to call all human beings Americans (or French or Italians or Russians, according to personal preferences) because they have the same general physiological or anatomical m a k e u p — two eyes, ten fingers, one nose, and so on. We still find a use for the national or racial designations and the name "American" still means something distinctive.

One must be extremely venturesome if he essays to have definitions adopted, in the field of metallurgy, without serious — perhaps even violent — controversy. Even at this risk I am going to propose something. This "something"

is not definitions, but rather grounds for classification of microstructures. I do not even think it is new, but rather a reiteration of old ideas. My alibi (business of controversy) is that in no case do I attempt to state just what composition of phases or what proportion of constituent phases constitutes the correct qualification for being included under the various terms. These matters I leave to others, who are (if possible) even more venturesome than I.

Distinctions, Rather Than Definitions

I propose the following *distinctions:*

Pearlite — The normal product obtained by slow transformation of eutectic austenite. It consists of the phases ferrite and cementite, the composition and relative amounts of these phases depending upon the proportions of other elements present, soluble in either phase, and upon the degree of approach to infinitely slow cooling.

Troostite and *Sorbite* — Recognizable and fairly characteristic microstructures produced by rapid cooling of iron-carbon alloys, or by reheating such alloys after they have been fully hardened. They consist essentially of the phases ferrite and cementite but, since these phases have formed under conditions of pronounced disequilibrium, and from alloys not necessarily of eutectic composition, the composition, relative amounts, and form and average crystal size of such phases depend upon the specific composition of the alloy and its thermal history.

It may be pointed out that I have here carefully avoided any statement that should be construed as an attempted *definition* of any of the three terms above discussed. Nothing has been said as to the degree of divorcement, if any, of pearlite and nothing as to "globular", "spheroidized", or other forms of pearlite. The desire is merely to keep "pearlite" as a name signifying mode of formation and general phase makeup, rather than definite elementary or phase composition. I do not know precisely what troostite and sorbite may be, to the last degree, and I doubt whether anyone else does, even though we do have some extremely useful ideas about these structures. We constantly attempt to broaden these ideas and to make our terms more meaningful. I do not know where that will end. Does anyone?

Martensite, it will again be observed, I have left (almost) strictly alone. In this device of detouring I am qualifying, as I see it, for the

definition of "American", as it was sneered at us by the French and English when they were trying to propagandize us into the late war: "An American is one whose religion is 'safety first'." (Even at this, I do not expect to escape without a few scars!)

There will continue to be, as in the past, structures whose classification will present difficulties. Just how nearly normal must pearlite be to justify its name? Just when, in the consideration of larger grain size and decreasing metastability, must we stop calling a microstructure "martensite" and change to "troostite" (or "troostite" to "sorbite", or "sorbite" to "pearlite")? With the exception of pearlite these structures are not definite, in the sense that phases are definite and distinct, any more than styles of architecture are definite and distinct. No other set of names could be much more satisfactory, and yet we need some such names — even though occasionally, in our puzzlement, we hedge slightly by using cumbersome terms like "troosto-martensite" or "sorbitic pearlite".

As was earlier remarked, I sympathize with Dr. Sauveur's general views. I do not believe that any serious schism is likely to develop among students of metallurgy or among workers in this field. Neither do I feel that attempts to extend the use of terms outside their former recognized significance should be regarded as "thrice-refined pabulum of transcendental moonshine", as Thomas Carlyle might say. We are all interested in the continued effort to improve our metallurgical language, to make it more definitely expressive, and this is the only reason for the present communication.

☻　　☻　　☻

Editor's Closure — No apology is necessary for giving so much space in this and preceding issues to the important problem of metallographic nomenclature. It appears to the Editor, however, that harmonization of personal preferences cannot be expected until the disputants are agreed on the experimental facts.

For instance, "Is it possible for hypo-eutectoid austenite to transform between Ar_1 and Ar' into anything but ferrite plus a lamellar mixture of ferrite and carbide?"

"Is the acicular structure resulting from transformation at some constant temperature between Ar' and Ar'' different from martensite?"

"Can martensite be converted on tempering into anything but a dispersion of cementite particles in a matrix of ferrite?"

Let discussion be confined, therefore, in the immediate future, to such points.

Efficiency of the Blast Furnace

By J. B. Austin

THREE of the four principal functions of an iron smelting furnace — namely, preheating, fluxing and melting — are essentially heating operations and therefore theoretically independent of the method of heating used. The coke-fired blast furnace is therefore in principle as efficient thermally as any other method. Any attempt to set up a bogey with reference to which the performance of a real furnace can be compared, would then hinge on the chemical operation of reducing iron oxide.

There are probably only three commercial possible reagents for this purpose, which act at 1650° F. as follows

$$Fe_2O_3 + 3H_2 + 134 \text{ B.t.u.} = 2Fe + 3H_2O$$
$$Fe_2O_3 + 3C + 2076 \text{ B.t.u.} = 2Fe + 3CO$$
$$Fe_2O_3 + 3CO = 2Fe + 3CO_2 + 339 \text{ B.t.u.}$$
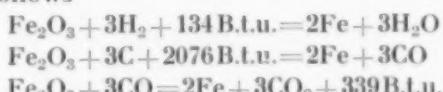
and from a thermochemical standpoint the blast furnace reduction by CO which evolves a slight amount of heat, is the best.

Turning now to the question of the efficiency with which the fuel is used, it will be necessary to calculate the minimum amount of coke for reduction and then see whether the heat generated by burning this coke will give sufficient heat to keep the furnace in operation.

From the last equation it can readily be figured that 720 lb. of carbon can react with 3210 lb. of Fe_2O_3 to give 2240 lb. of iron. But this cannot be done so simply because the reaction is reversible, and it is necessary to maintain a considerable excess of CO to keep the reaction going in the desired direction. Let us therefore imagine an ideal furnace as consisting of three chambers with connections for passing gas from one to another. In the first chamber Fe_2O_3 is reduced to Fe_3O_4, in the second Fe_3O_4 is reduced to FeO, and in the third FeO is reduced to Fe.

It is assumed that at the start each chamber contains enough oxide to yield a ton of iron, that all three chambers are at the same temperature (1500° F.), that the reducing gas contains only CO and CO_2, that all reduction is effected by means of CO. Referring to the equilibrium concentrations for the system $Fe : FeO : CO : CO_2$ we find that only 36% of the CO is effective for reduction of FeO. The reaction going on in the third chamber at 1500° F. is therefore

$$FeO + 2.8CO = CO_2 + Fe + 1.8CO$$

We start with 2880 lb. of FeO, and 1343 lb. of carbon is required, of which 480 lb. is for actual reaction and 863 lb. goes to maintain the indispensable excess of CO.

Similar reasoning and computations show that the residual gas is amply

A Battery of Reflux Condensers Used in Corrosion Testing
Photo by Rittase for the DuPont Magazine

Metal Progress; Page 222

By Vsevolod N. Krivobok

Associate Director of Research
Allegheny Steel Co.,
and Professor of Metallurgy
Carnegie Institute of Technology

Permanency of the

stainless steels

NOT SO LONG AGO, in conversation, an eminent metallurgist and engineer spoke thus of the stainless steels: "Their place in modern industry is assured because of their permanency." He did not add — because to him it would have appeared superfluous — " . . . providing service conditions are properly appraised, possible variations in such conditions taken into consideration, and the influence of the method of construction on the properties of the alloys carefully evaluated."

The idea of permanency without stated qualifications is neither justifiable nor technically sound. The mind acquires the expectation of permanency for certain kinds of metal because of the marked and profitable improvements in the life of equipment in various industrial processes through the use of special corrosion, acid, and heat resisting alloys. If the selection of the metal has been properly made, a correct method of construction has been used and the assembly received its due care after construction and in service, the expectation of permanency becomes a reality and the above quoted phrase a true estimate of the alloy's industrial importance.

A careless and over-optimistic attitude, in some form or another, is invariably found to be the reason for the rare cases of disappointment. That the last statement is not an exaggeration will be agreed to, I am convinced, by men actively promoting stainless steels, as well as by fabricators and users. The reasons for failure are not always apparent or easily ascertained; that fact however does not change the picture.

The known isolated cases of failures (in the exact sense of the word) are — not merely "may be" — traced to one of the following causes:

1. Misapplications, caused primarily by enthusiasm, partly by psychology and partly by the lack of knowledge.

2. Improper handling in construction, traceable to the failure to realize the fundamental characteristics of the metal.

3. Neglect or abuse of the metal once it is installed, including radical changes in the conditions of service.

Obviously it should be the desire of all concerned — manufacturers, fabricators and users — to make permanency more permanent (the reader will forgive this hyperbole!) through the intelligent approach and most careful consideration and individual study of each problem involving corrosion and, consequently, corrosion resistant steels and alloys. For this reason the theme of this and the two preceding articles (all portions of the paper entitled "Characteristics and Fabrication of Stainless Steels Containing More Than 14% Chromium" read before the Western Metal Congress early this year) has emphasized the properties and characteristics of the alloys with especial reference to the changes induced by the usual fabrication methods. Much, therefore, has been said about cold work and welding heat.

The first article in the July issue discussed the chromium-iron alloys, ferritic in microstructure, and the second one in August METAL PROGRESS considered the chromium-nickel steels, whose microstructure is a quasi-stable austenite. Microstructural stability of these is vastly enhanced by the addition of columbium or titanium. Alloys so modified occupy a prominent place in stainless industry. Their

discovery and subsequent commercial applications greatly diminished the hazards of corrosion induced by carbide precipitation. In other words, their use is for a specific purpose.

Effect of Molybdenum Additions

At present another modification of the chromium-nickel-iron alloys is receiving well deserved attention; it contains up to 3.5% of molybdenum. Generally the composition of the alloy would fall within the following limits: Carbon 0.12% max., chromium 16 to 20%, nickel 8 to 14%, molybdenum 2.5 to 3.5%. Its discovery and commercial applications are also traced to the necessity of having an alloy particularly suited to a specific case of corrosive attack: This refers to a local or pinhole type of corrosion shown in the view on page 224, distinctly different from general solution, or from grain boundary corrosion associated with carbide precipitation. In this type of attack single holes or pits appear when the metal is in contact with certain corrosive media; the rest of the metal is totally unaffected.

We know that pinhole corrosion is induced or accelerated by severe straining of the metal, such as a deep scratch or the cold shearing of the edges, but besides this the reason for this local selective attack is not yet known. Fortunately, alloys of chromium-nickel-iron with molybdenum offer a much greater resistance to it than any other stainless alloy and the properties and characteristics of this modified type should be described.

Unless the concentration of chromium and nickel is adjusted in the alloy, the addition of molybdenum promotes the formation of ferrite in the microstructure and the alloy becomes a two-phase alloy, with austenite however greatly predominating. In such an analysis as nickel about 12 to 14% and chromium about 17%, formation of ferrite is

suppressed and the alloy is austenite throughout even after the addition of 3% molybdenum. Consequently "molybdenum bearing alloys," as they are generally called, can show gradation in microstructure depending primarily upon the composition and, to some extent, upon heat treatment. Since the properties of the austenitic and ferritic phases are different, at both room and high temperatures, it is logical that the mechanical properties of the molybdenum stainless alloys will vary. Comparison of properties in the cold-worked condition is shown in the adjoining table for sheet of the same initial tensile strength in the annealed condition.

For the reasons of fabrication, alloys with molybdenum usually contain, as has been stated, higher nickel percentages than corresponding alloys without it. The response to cold working of such alloys will be different; alloys bearing molybdenum can be subjected to bending, forming, and other fabrication processes. Their properties, of course, are dependent upon composition, but, as a general rule, these alloys are not as pliable and ductile as corresponding alloys without molybdenum.

As in the Cr-Ni-Fe stainless steels the austenite of alloys with molybdenum is not a stable phase in a true sense of phase equilibrium. Consequently the latter alloys also have a range of temperature (corresponding, we
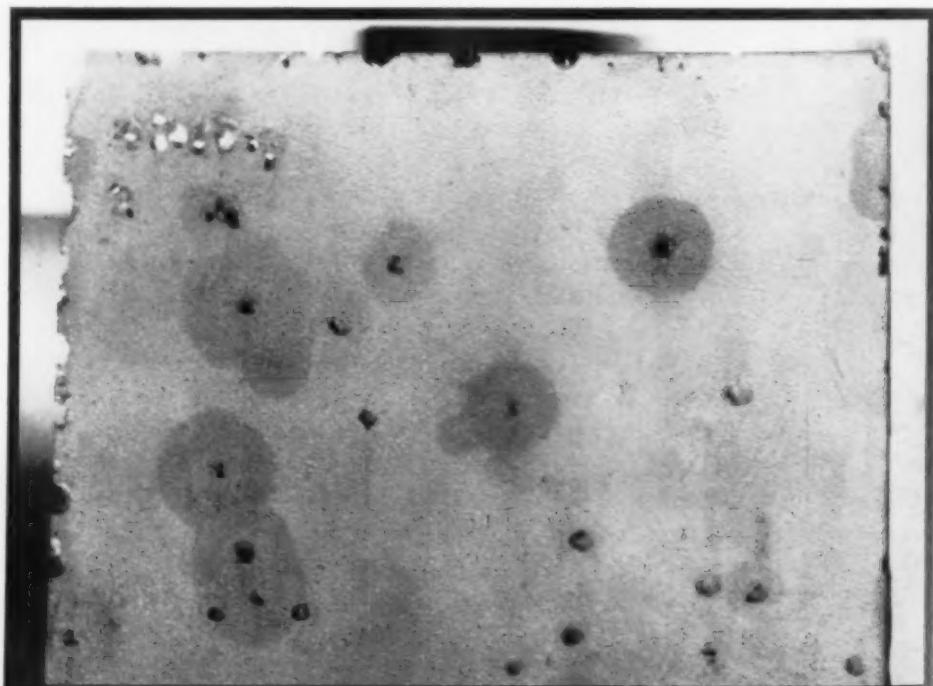
Example of Pinhole Corrosion in Sheet of 18-8 Stainless Steel. Attack has favored sheared edges and punch marks, but is nevertheless virulent at numerous spots on the original surface

believe, to that of the alloys without molybdenum) within which, given sufficient time, they undergo damaging structural and phase changes.

While such changes can be followed by

Tensile Properties of 18-8 Mo Sheet

	TENSILE STRENGTH		ELONGATION	
	18-8	18-8 Mo	18-8	18-8 Mo
Annealed	94,350	95,770	70	58
Cold worked				
10%	107,200	112,300	45	35
20%	127,000	128,000	30	18
30%	143,800	148,800	16	10
40%	164,900	163,900	9	5
50%	175,500	170,500	5	4
60%	194,500	183,500	3	3
Analysis: C	0.08	0.06		
Cr	18.10	18.17		
Ni	9.08	9.77		
Mo	—	3.09		

microscopic observations, they also affect the corrosion, and can be ascertained by the nitric acid test, as is shown in the second table for two representative alloys.

From these results it would appear that the maximum corrosion resistance is secured by heating to within the range 1850 to 2100° F. and rapid cooling. Data are not yet available showing the temperature at which disintegration — or rather, relative loss of corrosion resistance — proceeds w i t h maximum rapidity. The temperature of 1200° F., quite effective as is seen, was selected for the purpose of comparison with alloys without molybdenum.

Short time heating within certain range of temperatures (as in welding) may or may not affect the metal by causing carbide precipitation depending upon the composition of the metal, thickness, and other factors discussed in the August issue of METAL PROGRESS. The appearance of the metal in the weld and in the areas adjacent to the weld after being subjected to the action of corrosive solution composed of nitric and hydrofluoric acid is shown in the views on the next page representing two plates of the same thickness but of different analysis. Both were welded with welding rod of the same analysis

as the plate metal. One does not show any corrosion, either in the weld or areas adjacent to the weld, while the other does. Thus the influence of analysis on corrosion properties after welding (in this gage material) becomes obvious.

Merely for the purpose of comparison, a third view is shown, giving the appearance of columbium bearing material of much heavier gage and identically welded and treated; the very severe corrosion medium has done little more than etch the surface slightly to accentuate tool marks and bring out the ripples and grain structure in the welds.

Experimental work and experience permit us to make the statement that while the high chromium-nickel a l l o y s containing considerable molybdenum are not entirely free from the phenomenon of carbide precipitation, nevertheless they are not as susceptible to it as alloys of similar analysis without molybdenum. A direct comparison appears to be difficult, because the concentrations of chromium and nickel in the commercial alloys with and without molybdenum are not strictly comparable. Whenever the use of the alloys containing molybdenum is justified for construction purposes by their increased resistance to pinhole corrosion, such factors as the

Corrosion Resistance of 18-12 Mo Sheet

Inches penetration per month
based on three 48-hr. periods in boiling HNO_3.

	PRELIMINARY HEAT TREATMENT	ALLOY No. 1*	ALLOY No. 2*
A	2100° F., 15 min., water quenched	0.0035	0.0037
B	2100° F., 15 min., air cooled	0.0050	0.0040
C	1200° F., 1 hr., air cooled	0.092 to 0.174	0.105 to 0.114
	C followed by A	0.0033	0.0034
D	1500° F., 1 hr., water quenched	0.0250	0.0170
E	1850° F., 1 hr., water quenched	0.0038	0.0036

*Analysis: Carbon	0.07	0.07
Chromium	18.90	17.50
Nickel	11.40	12.40
Molybdenum	3.50	2.90

methods of construction, the gage of the metal, the possibility of annealing treatment, the nature of corrosive agents and the actual conditions of service, including the possible variations, should be most carefully considered.

In order to maintain resistance to pinholing and yet to minimize the susceptibility to corrosion induced by the precipitation of carbides, a further modification in the analysis, namely adding columbium to molybdenum b e a r i n g alloys, is receiving attention. While the stabiliz-
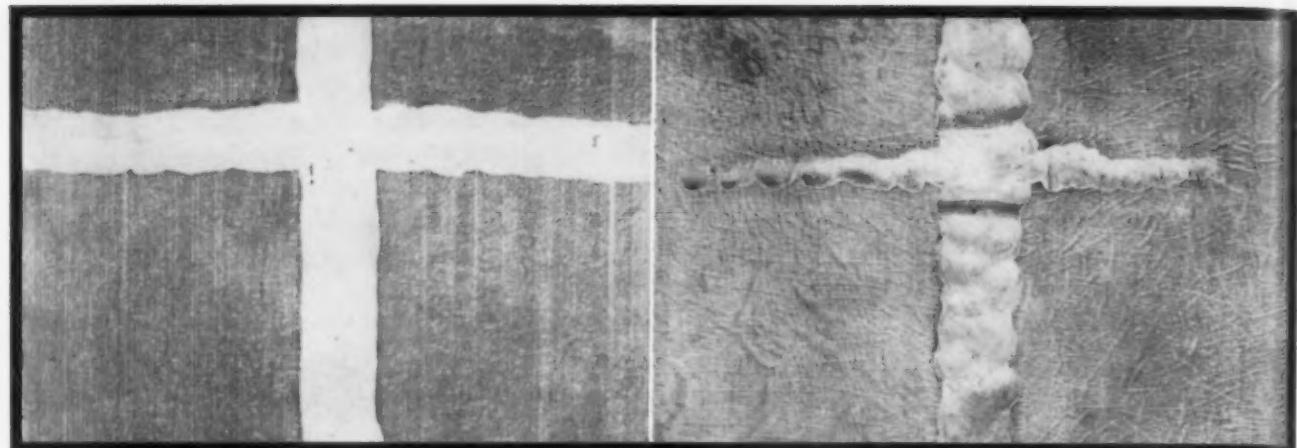
19% Cr, 12% Ni, 3% Mo Alloy (Left) and 17.5% Cr, 12% Ni, 3% Mo Alloy (Right), Welded With Rods of Respective Composition. Appearance after four 30-min. periods of immersion in solution of 10% HNO₃ plus 4% HF at 140° F.

ing effect of columbium is quite evident, thorough testing of the alloys and studies of their characteristics are not yet completed. It is too early to consider this modified alloy as a commercial product.

Several other modified alloys of the austenitic type should also be mentioned. None of them are free from carbide precipitation, and the previous discussion of this phenomenon applies in full measure to the alloys now to be mentioned.

Additions of silicon are recommended when increased resistance to high temperature oxidation is required. Usually the alloy contains up to 3% silicon, the beneficial influence of which asserts itself at temperatures above 1650° F. A. M. Borzdyka in a book in Russian on the heat resisting steels (1937) compares plain 18-8 with the same containing 2.5% silicon, and arrives at the conclusion that the steel with silicon loses only half the weight that plain 18-8 loses at 1800° F., and only one-tenth as much at 2000° F. He recommends an alloy containing 0.10 to 0.15% carbon, 25% chromium, 20% nickel, and 2.5% silicon. Additions of aluminum are said to improve its oxidation resistance still more.

("Said to improve" was deliberately phrased, because a study of the available experimental data shows a vast influence of the nature of the atmosphere and the necessity for a proper balance between the silicon and aluminum in the analysis. It should also be realized that aluminum has a detrimental effect on mechanical properties at high temperatures, considerably lowering the ductility.)

According to foreign investigators 0.5 to 2.0% molybdenum in chromium-nickel alloys improves the oxidation resistance within the range of temperatures from 1650 to 1900° F. Tungsten additions do not appear to make much difference; both elements, however, are recommended, mostly again on the continent, for increasing strength at high temperatures as measured by short time tests and creep tests.

It is also suggested by European investigators that the composition of the alloys may be reversed in nickel and chromium. Of these modifications a large group has been investigated and an alloy containing 13% chromium, 26% nickel and 3% tungsten is offered as possessing the pre-requisites for high temperature service. This is suggestive of the American alloys (say 38% nickel, 18% chromium) for castings to resist relatively high temperatures, as in mechanisms for heat treating furnaces.

Chromium-Manganese Steels

In several countries the substitution of manganese for nickel has received much attention, mostly because of economic considerations. At present, chromium-manganese steels are tentatively divided into the following groups.

1. (a) 15 to 20% Cr and 8 to 12% Mn.
   (b) Same with additions of Ni, Mo or W.
2. 25 to 30% Cr and 12 to 16% Mn.

Work in this country as well as abroad has shown that additions of manganese to alloys with, let us say, 18% chromium must be considerably higher than similar additions of nickel in order to have the alloy composed of only one phase, austenite. A striking illustration will be provided by the comparison of these alloys: 25% Cr, 12% Ni, 0.10% C is completely aus-

⅜-In. Plate of 18-8 Stabilized With Columbium After Cross Welding With Rod of Same Composition and Exposed Four 30-Min. Periods in 10% HNO₃ and 4% HF at 140° F. Composition: C 0.055, Cr 18.73, Ni 9.74, Cb 0.68
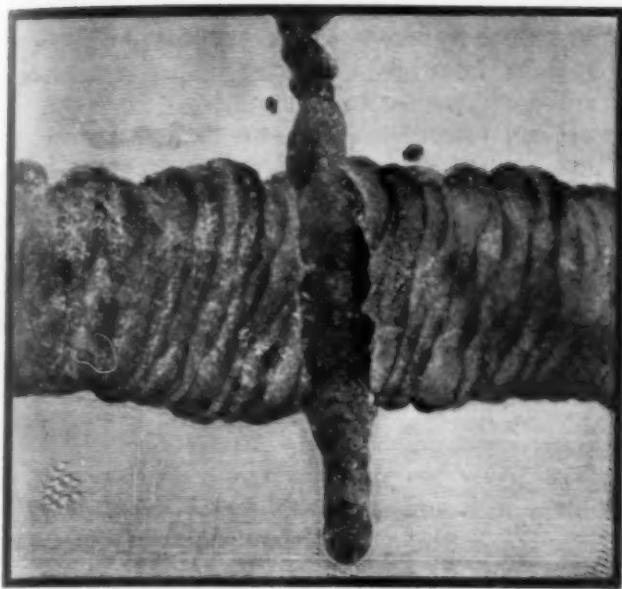
tenitic; 25.9% Cr, 11.2% Mn, 0.15% C is ferritic, although a compound (Fe,Mn) Cr may also be present in small amounts. Further, the "stability" of austenite in chromium-manganese steels is of a lesser degree. For the presence of austenite only, one must (a) increase considerably the manganese or carbon content, (b) decrease the chromium content, (c) effect partial substitution of nickel for manganese.

Perhaps it should be mentioned that the single phase, austenitic structure is desired because of the mechanical properties and characteristics of the alloys. Such steels are readily cold worked and because of the above mentioned "lesser stability" show considerable increase in tensile strength even after moderate amount of cold work. As in the case of chromium-nickel steels, various properties of chromium-manganese steels at room temperature are much dependent upon the analysis. Unless the manganese content is high the steels are not structurally austenitic and upon annealing from various temperatures show a brittleness that is identified by reduced impact values.

It is believed that chromium-manganese austenitic steels have generally somewhat higher strength at high temperatures than the chromium-nickel austenitic steels. Recently published work seems to show that high strength at temperatures up to 1800° F. is obtained by adding from 2 to 2.5% of either molybdenum or tungsten. In fact it is definitely claimed that high temperature properties of the alloys with

the general composition Cr 15 to 16%, Mn 10 to 12%, W 2 to 2.5% are superior to those of the chromium-nickel austenitic group with or without similar additions of tungsten.

Resistance to corrosion by various chemicals at room or at elevated temperatures is not as good as that of chromium-nickel steels, as has been proven by laboratory tests. This does not deny that the chromium-manganese steels are useful for certain applications where economic considerations are of primary importance. In America, where such natural or artificial shortages of nickel do not exist, the substitution of manganese for nickel does not appear warranted.

Chromium-manganese steels are susceptible to carbide precipitation within about the same temperature range as its prototypes. Hence it is imperative to remember the precautions which were discussed in connection with welding or high temperature use.

Resistance to scaling or oxidation at high temperatures is less than that of the chromium-nickel steels, especially if the latter are modified by the additions of silicon. This is clearly shown by the curves below representing experiments by Schmidt and Legat. In fact the proponents of chromium-manganese steels
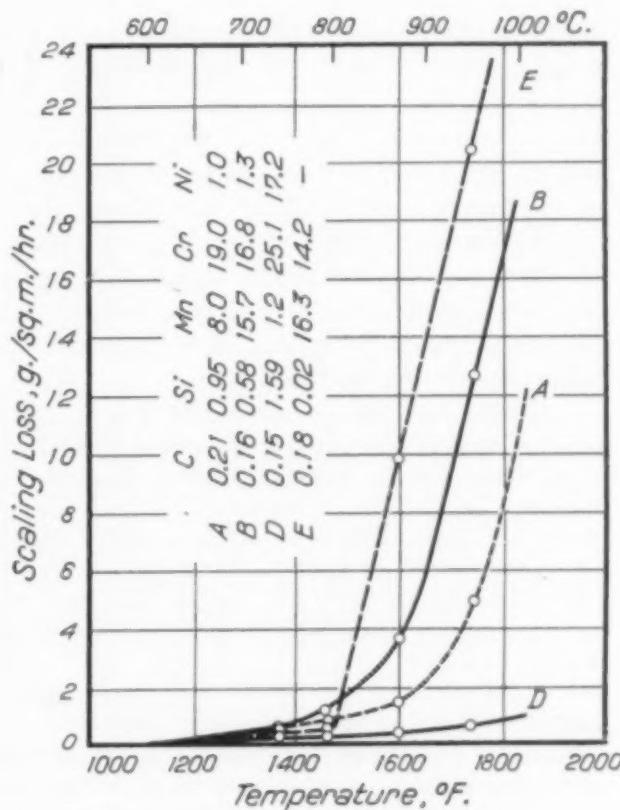
Comparative Oxidation Losses of Cr-Ni, Cr-Ni-Si, and Cr-Mn Steels After 72 Hr. Exposure to Air at Given Temperatures

do not recommend their use for continuous service at temperatures higher than 1500° F., but urge their consideration at lower temperatures, primarily because of their strength when heated and their resistance to sulphurous gases.

Conditions Required for Permanency

Reverting now to the idea expressed at the outset, the reader is again cautioned against indiscriminate expectations when the use of "stainless," "rustless," "corrosion resisting," and "heat resisting" is contemplated. It is of course understood that no alloy exists which is equally resistant to any and all corrosive media and under any and all conditions.

Whoever first coined the word "stainless" was, without question, an enthusiast — justifiably one, because the *relative* resistance to corrosion or oxidation is so vastly improved as to inspire one to enthusiasm. The word "relative" applies not only to the comparison between stainless steel and, let us say, iron or aluminium or brass, but also to the effect of various corrosive media on the stainless alloys themselves. To assess this one aspect of the alloys, both by research and in practical applications, is a truly enormous task. A vast amount of data is now available upon request; a vast amount is yet to be determined. In evaluating such data it is imperative to take into consideration every factor that may influence corrosion, or resistance to corrosion, one way or the other. These factors are not always appreciated, because in most cases it is very difficult to estimate them.

A happily coined word "environment" embraces the sum total of the factors influencing resistance to corrosion or the rate of corrosion. Among the main influences of environment the following should be listed:

1. Nature of the corroding media.
2. Concentration of the corroding media. In general an increase in concentration increases the rate of attack, often up to some maximum value after which the attack is diminished. If the change in concentration produces some other changes in the corrosive media (its oxygen content, for example) the progress of corrosion may not follow the above simple rule.
3. Temperature of the c o r r o d i n g media. Increase in temperature usually intensifies the attack, but sometimes, for example, the products of corrosion become more soluble in the corroding media, and different results may be encountered.
4. Hydrogen ion concentration (pH value) of corroding media usually increases the rate of attack.

In certain experiments with stainless steels, keeping the pH value above 7 (the value for a neutral solution) resulted in immunity to corrosion.

5. Oxygen concentration. An increase in oxygen content may either increase or decrease the probability and rate of attack, depending upon other circumstances present.
6. If liquid and vapor phases are present, the alloys may be immune in the liquid and attacked by the vapors. Even slight changes in the concentration of vapor may shift the metal from "passive" (unattacked) to "active" (attacked). A known special case is the one when SO_2 in the presence of air, has little effect upon the metal at high temperatures, yet severely attacks it if the vapor is allowed to condense.
7. Stagnant or agitated corroding media have, sometimes, different rates of attack.
8. Deposits of products of corrosion cause a specific case of localized corrosion, usually attributed to the deficiency of oxygen at the point of contact — a special case of "contact corrosion."
9. Change in conductivity, usually caused by changes in concentration or temperature.

Besides the above the following "conditions of environment" should be kept in mind:

1. Homogeneity of the metal.
2. Susceptibility of the metal to structural alterations upon heat treating. A particular case would be carbide precipitation in chromium-nickel alloys.
3. Freedom of the metal from internal stresses. Cold working of the material may result, in some corrosive media, in (a) increased over-all corrosion, (b) local or so-called stress-corrosion, and (c) intercrystalline corrosion.
4. Preparation of the surface of the alloy.

Thus, as was stated at the very beginning of this article, it is most important to give due consideration first to the proper type of the alloy and, second, to all factors that may be altered in the actual performance of the commercial process. Selection of the alloy should always be made with certain factors of safety, so that inevitable small changes in temperature or in concentration of corrosive agent or some of the other enumerated factors will not change the metal from "passive" to "active." In the multitude of applications, as is attested by the thousands of tons of stainless alloys annually sold, this factor of safety is an inherent characteristic of the alloy; that is, unless a *radical* change in service conditions or environment is allowed to occur, the anticipated life and performance will be realized. If it was thought important to list various factors which *may* cause unexpected difficulties, it is only because one should accept

the wisdom of the adage "to realize danger is the best way to avoid or prevent it."

Applications to service at high temperatures should also take into consideration various important factors among which are:

1. The temperature of service. Austenitic alloys are not recommended for service within the temperature range of carbide precipitation (800 to 1500° F.) unless modified with titanium or columbium. Straight chromium alloys should be used instead, subject to other considerations listed below.

2. The nature of the hot atmosphere, whether oxidizing, reducing, or containing other gases. If, for example, sulphur compounds are present in the atmosphere, plain chromium alloys should be used. Another example is the possibility of carburization at high temperatures.

3. Intermittent or continuous type of service, and the manner of cooling in intermittent service. This is particularly important if condensation is likely to occur. A specific example was already considered in the discussion of pinhole type of attack. As rough approximations, the scaling temperatures of the plain chromium irons in continuous service are 1450 to 1500° F. for the 16 to 20% Cr, 0.12 max. C alloys and 1900 to 2000° F. for the 25 to 30% Cr, 0.30 max. C alloys; scaling temperatures in discontinuous service are about 100° higher. For the chromium-nickel alloys (0.20% carbon max.) 1600 to 1700° F. represents the scaling temperature in continuous service for the 18-8 type and 2000 to 2100° for both the 24-12 and the 25-20 types.

4. The mechanical characteristics required at room temperature after service at high temperature. Chromium alloys may develop brittleness to impact after having served at high temperatures and then cooled; thus they should not be used in cases where high resistance to impact is the prerequisite mechanical property.

5. Such characteristics as coefficient of thermal expansion. This is particularly important in intermittent service, but each case should be considered separately. In several cases the use of straight chromium alloys was imperative.

6. Mechanical properties (creep) at high temperatures, the importance of which is self evident.

The above factors, responsible for the satisfying performance of a chosen alloy under contemplated conditions, have been briefly illustrated by appropriate examples. That any such example should not be used as an absolute criterion will, of course, be realized. For example, a possibility of condensation and its harmful effect on metal will obviously be dependent on concentration of the corroding compound in the gas. It may be necessary to test alloy samples under actual conditions of service — even build small pilot plants — a practice quite generally adopted by important consumers.

However, the general corrosion characteristics of the alloys can be gaged by certain standard methods, which allow us not only to discover the best condition of a particular alloy to resist corrosion, but also to check on the processing of metal and methods of construction. Among these tests the following are in common use:

1. Boiling concentrated nitric acid, usually carried out as three or five separate tests, each of 48 hr. duration. The results are calculated as losses in weight and reported as inches penetration per unit time. While it was designed to test general resistance to corrosion, the method is also used to verify the freedom of austenitic alloys from the bad effects of precipitated carbides.

2. Subjecting the alloy, in refluxing condenser, to the action of boiling copper sulphate and sulphuric acid of certain concentrations. This is used for the purpose of detecting precipitated carbides, often in the welded material.

3. Immersion of samples into solution of 10% nitric and 4% hydrofluoric acids either at 140° F. or boiling. Different concentrations are sometimes used and the length of immersion varies. This is used primarily for the purpose of evaluating the characteristics of the welded metal.

4. Immersion in ferric chloride solutions (different concentrations, at times modified by additions of sodium chloride) to judge the resistance to pinhole corrosion.

5. Salt spray for general corrosion resistance.

These tests vary in severity. Their use and especially the evaluation of the results should be done in the light of the applications for which the alloys are intended. For instance an alloy of 25% chromium, 20% nickel, ⅞ in. thick, welded plate, tested in $HNO_3 + HF$ acid *at 140° F.* does not show any defect whatever in the area adjacent to the weld, yet the same alloy tested in the same solution *boiling*, shows a very slight attack a short distance from the weld. To say on the strength of the second test that this alloy would be unsuitable in applications involving comparatively mild corroding media such as dilute solutions of nitric, acetic or lactic acids would be totally unjustifiable.

*   *   *

By Walter F. Hirsch
Chief Metallurgist
Industrial Research Laboratories, Ltd.
Los Angeles, Cal.

Nickel-boron cast iron

for resistance to

abrasion

IN 1931 the attention of Industrial Research Laboratories was d i r e c t e d to the unusual properties of a species of white iron produced from a low grade iron ore. It was considerably harder than ordinary white iron and chemical analysis disclosed the absence of other metals such as tungsten, chromium or molybdenum which might ordinarily account for its hardness. Further investigation revealed the presence of boron unknowingly introduced during the melting of the iron by prolonged heating in a plumbago crucible under a heavy cover of borax. Under these conditions (as was subsequently found by further experimentation) boron is readily reduced from the borax and dissolves in the iron, the reduction being accomplished by carbon and silicon present in the iron or absorbed from the crucible. The resulting alloy closely resembles white iron, but exceeds it in hardness and is more or less brittle, depending on the percentage of carbon and boron present.

Search through the literature and elsewhere disclosed that boron had not been used commercially in ferrous alloys up to that time and was generally regarded as a valueless addition which rendered the iron hopelessly brittle when added to the extent of 1%. Preliminary tests indicated that the iron-boron alloys had excep-

tional abrasive resistance and it was felt that there must be applications where they could be used to considerable advantage.

A systematic research was begun to determine the effect of changes in composition on the physical properties of these new alloys. The metallographic phases of this investigation were conducted under the direction of Donald S. Clark of the faculty of California Institute of Technology. This research resulted in an alloy, now rather extensively used for its abrasion resistance. The alloy, its method of production, and the resultant products are patented, and produced by the Industrial Research Laboratories under the trade name "Xaloy," and by Wilcox-Rich, licencee for machine and engine parts. The trade name "I.R. metal" is used by Oil Well Supply Co. and Alford Sales and Service, Ltd., licencees for pumps and accessories used in oil field equipment. Its composition is usually maintained within the following range: Carbon 2.50 to 3.25%, boron 0.70 to 1.10%, silicon 0.50 to 1.50%, manganese 0.50 to 1.25%, nickel 3.50 to 4.50%, phosphorus 0.05% max. and sulphur 0.05% max.

In our research the iron-carbon-boron system was first investigated and the useful commercial limits established. Then the effect of several additional elements was determined, and nickel was found to have the most beneficial action when used in moderate percentages.

The lower curve in the diagram shows the effect of nickel additions on the hardness of a plain white iron, the composition of which was as follows: C 3.20%, Si 0.50%, Mn 0.60%, P 0.05% and S 0.015%. Hardness values in the diagram are expressed in terms of diamond Brinell hardness and were determined on a Shore monotron. The test pieces were sand cast and air cooled. The base metal had a white

fracture. Additions of nickel resulted in a gradually increasing amount of graphitization causing a corresponding drop in the hardness. Nickel in higher quantities also aids in the formation of martensite and so the hardness values do not drop beyond a certain point.

The upper curve shows the effect of nickel on the hardness of an iron-boron alloy of the following composition: C 3.00%, B 1.00%, Mn 0.60%, Si 0.57%, P 0.050% and S 0.015%. In all these experiments, casting conditions and cooling of the test specimens were the same. The remarkable hardening effect of the nickel on the iron-boron-carbon alloy is at once seen.

When boron is added to iron-carbon alloys, it effectively prevents graphitization unless the silicon is unduly high. As little as 0.25% boron added to an ordinary gray iron will render it white. Boron apparently enters into combination with the cementite greatly increasing its stability. If the iron is hyper-eutectic there may be some graphitization of the pro-eutectic cementite on solidification, but the remaining cementite is stable and will not break down even on prolonged annealing at high temperatures. With normal rates of cooling the austenite transforms to pearlite.

When 4% nickel is present in such an iron-carbon-boron alloy, the structure of an air cooled piece consists of martensite and cementite as can be seen in the micros on page 232. The boron overcomes the graphitizing tendency of the nickel and restricts the effect of the latter to the production of martensite in place of pearlite.

The commercial nickel-boron iron Xaloy can be produced in several ways. It can be made either by melting plain iron and adding ferroboron and nickel, or adding a nickel-boron, or by the direct reduction of boron into the melt (4% nickel-iron) from a thick flux of borax, boric acid or other boron compounds. The direct reduction process is the one used almost exclusively by Industrial Research Laboratories. By closely controlling the temperature and time of

High Nickel Is a Softener in White Cast Iron, But About 4% Induces Extreme Hardness in a Similar Iron Containing About 1% Boron

heating and all melting conditions, consistent production within narrow limits of chemical composition is possible.

The physical properties are as follows:

Melting point	1975° F.
Tensile strength	30,000 to 45,000 psi.
Compressive strength	225,000 psi.
Transverse strength	37,500 lb.
Specific gravity	7.58
Thermal expansion	7.2×10^{-6} per °F.
Thermal conductivity	7.5 B.t.u. per sq.ft. per °F., per ft.
Hardness	800 to 950 diamond Brinell, or Rockwell C-64 to C-70

A series of wear tests was run by Robert B. Freeman at the California Institute of Technology, a full account of which was given in METAL PROGRESS, March 1937. He used a small stationary specimen (which could be accurately weighed for losses) against a rotating ring, thus inducing pure sliding friction. Speed, pressure and time were accurately controlled. Testing was done in a bath of petroleum distillate, a liquid of low lubricating power, but a coolant as well as a medium to wash away fragments of abraded materials.

These tests indicated in advance the findings in later service as pump liners, plungers, bushings and cylinder sleeves — namely that the new alloy when run against itself or against materials formerly used (such as nitrided steel, casehardened steel, or hardened alloys) had a much lower "wear factor" and consequently longer life.

Method of Lining Tubes

After an exceptional wear resistance had been established the next problem was to develop means of application. Its low melting point (about 100° F. below eutectic cast iron) suggested the possibility of its use in a process, previously patented by associated interests, for coating steel cylinders, either externally or

internally with another metal of lower melting point, forming a well-bonded composite article.

In carrying out the process a steel or iron tube or cylinder of the required size is used and one end is sealed by welding in place a head or cap. The calculated amount of alloy is then introduced in the form of small clean pieces. The other end is also sealed, this end containing a small central vent. The tube is then placed in a furnace and heated to a temperature of 2150° F. while being slowly rotated. This heating is continued until the alloy is completely molten, and takes from about 5 to 30 min., depending on the size and thickness of the steel tube and on the amount of coating to be applied. The tube is then quickly withdrawn from the furnace and placed in a spinning machine and rotated at a sufficiently high speed so that the molten Xaloy is thrown to the inner wall where it solidifies.

Rotation can be stopped as soon as solidification is complete. Normally the tube is air cooled, and is finished in this condition without further heat treatment. The average thickness of internal alloy is $\frac{1}{16}$ in., but this can be varied from 0.02 to 0.25 in. or even more as desired.

When cold the ends are cut off with thin abrasive wheels. The inside surface may then be finish ground or honed to the desired size, and for this some very precise special machinery, both horizontal and vertical, has been constructed. The untouched surface, as spun, is very true as to roundness and straightness, so only a small excess of material need be added for finish. This allowance varies from 0.010 to 0.050 in. on the diameter depending on the size of the cylinder. Removal of this amount of stock is sufficient to permit the production of a mirror-like surface free from defects.

Mutual Diffusion in Alloying

As prepared for lining tubes, the alloy is hyper-eutectic in microstructure. In this condition it is coarsely crystalline and rather brittle. During the heating, wherein the tube virtually serves as a melting crucible, a certain amount of the steel wall is dissolved. The effect of this is to reduce the carbon and boron content to the point where the microstructure becomes hypo-eutectic, whereupon the fracture is fine grained and the texture is such as to have extreme resistance to abrasion. The coating so applied is perfectly bonded to the steel base and will not flake off even under extreme deformation.

A cylinder having a hard surface coating applied in this manner has many advantages over one treated by the ordinary methods of producing a hard case. In the first place the wearing surface can be made much thicker than is practical by other means. Secondly, the hardness of this coating

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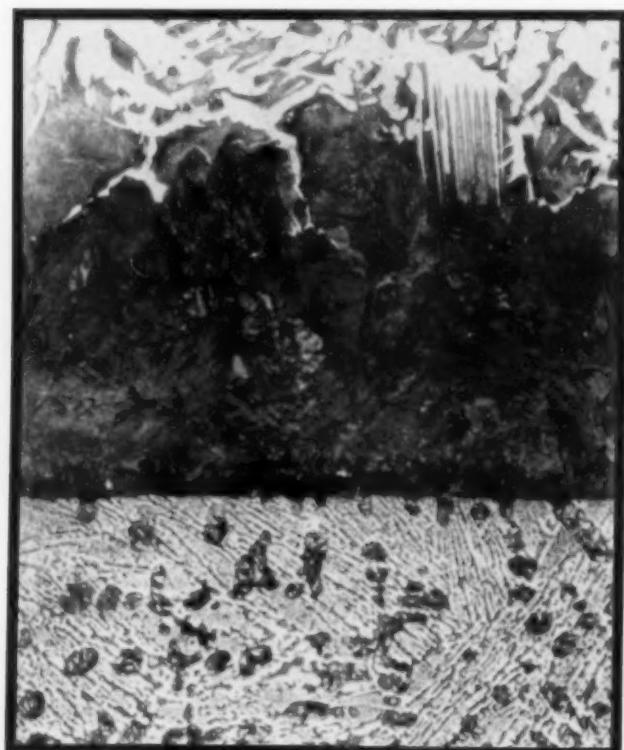
Low Carbon Steel, Above, and Nickel-Boron White Iron Below, With Transition Zone (Eutectoid Alloy Steel) at the Joint. Magnified 200 ×

Microstructure at 400 Diameters of Intensely Hard White Iron Containing 3% Carbon, 4% Nickel and 1% Boron. Areas of acicular martensite exist in white groundmass of cementite. Eutectic (originally cementite and austenite) has also transformed to cementite and martensite

Correspondence

What Is a Metallic "Surface"?

PARIS, *France* — It might appear superfluous to put the question: "What is the surface of a metal and how may it be characterized?" yet it is necessary when one undertakes to study the effect of surface condition upon properties of a metal. It affects not only properties associated with surfaces (optical properties such as reflectivity, emissivity, diffusibility; photo-electrical properties; capillary properties such as surface tension, wetting, greasiness; mechanical properties such as friction, wear, abrasion, fit; chemical properties such as solution potential and corrosion; catalysis; electrodeposition; contact electrical resistance) but also affects the mechanical properties of a mass of metal, such as elongation and yield point, but more especially impact brittleness and endurance under cyclic stress.

The answer to this question will vary according to the scale or unit of measure chosen to evaluate the dimensions, as follows:

1. The atomic scale, in which the atomic nucleus has significant dimensions and for which a convenient unit of measure is the tenth of an Ångstrom (10^{-1}Å or 10^{-8} mm.).

2. The submicroscopic scale, in which the atom, although still of significant dimension, is small, and in which the unit may be 100 Ångstrom units or 1 hundredth of a micron (10^2 Å or $10^{-2}\mu$ or 10^{-5} mm.).

3. The microscopic scale directly discernible to our senses with the instruments at our disposal, which goes from the micron (μ or 10^{-3} mm.) to a tenth of a millimeter (10^{-1} mm.).

Each of these domains or scales carries an explanation, valid only in that scale, of certain phenomena or particular properties; the whole constitutes the complete definition of a surface.

1. In the atomic scale, the atoms are regularly distributed in space according to the crystalline lattice; among them circulates the immense flux of the free or conducting electrons. This problem presents two aspects — the electronic and the atomic.

Under the electronic aspect, the surface of the metal is the potential barrier, containing the free electrons within as a skin holds gas; this potential barrier explains the Volta effect that when two metals are in contact, one assumes the positive and the other the negative electrical condition. However, electrons may be made to escape by various means, such as applying a strong electrical field, by furnishing them with heat energy (thermionic effect) or light waves (photo-electric effect). With such moving electrons are associated the Broglie waves, giving rise to electronic refraction by the potential barrier, a phenomenon brought to light by Davisson and Germer.

Under the atomic aspect, the surface of the metal is a region in which the equilibrium of atoms close to the outer space is different from the equilibrium of the completely surrounded interior atoms. This results in distortion of the crystalline structure and deformation of the lattice with decreased density — the atomic bonds of the exterior atoms are incompletely saturated, affecting two factors: *(a)* The orientation of the layers deposited on the surface of the metal, whether metallic layers deposited by electrolysis or oxide layers whose lattice corresponds to that of the metal; *(b)* the adsorption and firm retention of foreign atoms. (As an example of the latter, in order to secure stable optical, thermo-electric and photo-electric properties at the surface of a platinum test piece, it must be heated for hundreds of hours in a nearly perfect vacuum at 1000° C.). The adsorbed atoms diffuse into the metal atoms, causing fresh distortion of the crystalline lattice.

2. In the submicroscopic scale are found problems of contact, polishing and greasiness.

When two surfaces are in "optical contact," the space between them is so small as to assume the proportions of the wave length of light, less than a hundredth of a micron ($10^{-2}\ \mu$ or 10^{-5}

mm.). With such contact, adherence of polished surfaces is so great that stresses up to 700 psi. are necessary to separate them.

Polishing causes a superficial disturbance known as Beilby's layer; Rayleigh has shown optically on polished quartz the existence of a more refractive layer (refractive index of 1596 instead of 1460) to a depth of about one twentieth of a wave length (10^{-5} mm.) which disappears on etching with hydrofluoric acid.

On the other hand Darbyshire and Dixit, French, and other authors have established, by electronic diffraction experiments, the existence of an amorphous layer about 30 Å (10^{-5} to 10^{-6} mm.) thick. According to Bowden and Ridler, this can be explained by the high temperature of the surfaces during polishing, which may reach the melting point.

Spreading a lubricant over the polished surface of a metal produces a film formed of oriented mono-molecular layers, the mutual sliding of which explains the phenomenon of greasiness. Grease films have a thickness of about 100 Å (10^{-5} mm.).

3. Finally, in the microscopic scale, perceptible to the senses, the surface of the metal may be considered under three aspects — geometric, physical, chemical.

Geometric modifications are those which concern the degree of roughness or polish. They may be measured by micrographic, mechanical, optical, acoustic, pneumatic, or electrical methods (see METAL PROGRESS, June 1934, p. 44); they are the result of mechanical preparation of the surface (machining) or chemical preparation (pickling, etching).

Physical modifications comprise cold working, recrystallization, and quenching, and are the result of mechanical or thermal treatment.

Chemical modifications may be either intentional (cementation, nitriding) or accidental (decarburization) or may result from use or from the effects of the atmosphere (oxidation, sulphidation, corrosion).

All these modifications affect the surface properties as well as the mechanical properties enumerated at the beginning (see also METAL PROGRESS, April 1933, p. 51).

Thus, it can be seen that the surface of a metal may be entirely different from the mass when considered from all viewpoints and on all scales, and that it is of the highest importance to study and define it under all its aspects.

ALBERT PORTEVIN
Secrétaire Général de la *Revue de Métallurgie*

Big-Top Induction Furnaces for Clean Melts

TURIN, *Italy* — Many of the disappointing results obtained in European steel melting shops using the high frequency, coreless induction furnaces may be ascribed to the fact that the peculiar thermal conditions under which the metal bath is heated did not always receive adequate consideration. This often happened even where the furnaces were used for simple melting processes. It is only too obvious that still more serious disappointments occurred when such induction furnaces were used for refining purposes — where, of course, complex chemical and metallurgical processes take place in the metal bath.

At first, the high frequency furnace was usually welcomed as a simple return to the crucible; it was "the ideal crucible heated from inside," "the furnace where nothing is lost," and was therefore used exactly as a traditional crucible furnace. However, further and more careful observations showed that the working of the new "crucible" had — from the metallurgical point of view — very few analogies with the old. In fact, the only important analogy was the fact that in it nothing was lost!

In some instances the troubles arising from non-metallic inclusions, woody transverse fractures, low elongations, and the defective hardening of high speed steel, were so serious that the new furnaces could produce only steel of medium quality, thus changing radically the purpose for which they had been adopted.

A closer study of the thermal and metallurgical processes taking place in high frequency furnaces soon eliminated completely what might be called the original "crucible mentality", and the real and unique technical and economical advantages of the new furnaces were finally "discovered". Regulation of current intensity during the various stages of a heat had the result of eliminating the troubles connected with the "skin overheating" when this local overheating was controlled during the periods when its effects (such as the reactions on furnace lining and the stirring of the bath) were more injurious to the quality of the products.

The result was a complete elimination of the quality troubles which had been experienced in the beginning.

In addition to these technical improvements which had fully restored the likeness of

the new furnace with its glorious parent, the crucible, it was "discovered" somewhat later that this new furnace showed remarkable economic possibilities. These are due not only to the practically negligible heat losses of high frequency furnaces, their very low power consumption, reduced expenses for maintenance, repairs and labor, but especially to the fact that, by conveniently combining two or more furnaces, it is possible to obtain the best possible load factor and the maximum output from a given plant for given labor costs.

Under these conditions, high frequency furnaces have been gradually introduced into European steel foundries, even for the production of normal castings of medium quality. The costs obtained have been so encouraging that several large scale experiments are at present being conducted in the mass production of large ordinary steel castings.

It is obvious that in this new field, where cheap raw materials must be used, the peculiarity originally claimed as the greatest advantage of high frequency furnaces — namely, of being "a real crucible, where nothing gets lost" — loses its merits totally. In fact, attempts are now being made to modify the design in order to obtain good working conditions and facilitate the desired reactions between slags and metal!

Among the different types of furnaces for this purpose, one designed by Victor Stobie of Harrogate, England, seems to have given very interesting practical results. Design of the Stobie furnace, and of other similar ones, is generally based on the following principles:

1. Keeping the slag layer separated from the heated crucible walls.

2. Increasing the thickness of refractory linings where these are subject to the action of slags.

3. Facilitating repairs of refractory linings in the parts exposed to slag corrosion.

4. Dampening the movements of the metal bath, especially at its surface.

These conditions are fulfilled in the Stobie furnace by limiting the induction coil to the lower part of the crucible, while the diameter of this is increased in its upper part. Results obtained seem to be very encouraging. Starting with a charge of ordinary scrap with 0.6% carbon, 0.3% silicon, 0.7% manganese, 0.05% phosphorus and 0.05% sulphur, and working with two successive lime-sand slags and with additions of iron ore, a well-deoxidized final bath can be easily obtained containing 0.03%

carbon, traces of manganese, 0.02% phosphorus, 0.03% sulphur and 0.20% silicon.

Other types of furnaces, designed with similar general aims in view, are at present under experiment. In some of them, special attention is paid to the proper control of the furnace atmosphere.

FEDERICO GIOLITTI
Consulting Engineer; Bessemer Medallist

Constituents of Steel

CAMBRIDGE, *Mass.* — In METAL PROGRESS for August 1938 Professor Dorn describes martensite as a solid solution of carbon in alpha iron. It is difficult to conceive the existence of a solid solution so excessively supersaturated as, for instance, 0.80% carbon dissolved in ferrite (alpha iron). That such solution does form in the quenching bath as the result of the allotropic transformation of the solvent is likely, but it must be immediately followed by precipitation out of solution of carbide particles of submicroscopic dimension ("critical size," if you wish) resulting in great hardness such as we know martensite to possess.

This seems to me to be the most rational conception of the nature of martensite.

Professor Dorn proposes to give the name of pearlite to any lamellar structure of iron-carbon alloys quite regardless of its carbon content, thus severing all relations between pearlite and eutectoid composition. In my opinion pearlite does not form until eutectoid composition has been reached, at least approximately, and that in spite of the detection in hypo-eutectoid steel under very high magnifications of isolated regions exhibiting the structure of pearlite, because I believe that it signifies that in those regions eutectoid composition has been attained through rejection of excess ferrite. Pearlite, a eutectoid — that is, a eutectic-like constituent — is, like all binary eutectics, made up of two components substantially in constant proportions.

B. L. McCarthy, on page 149 of the same issue, seems to attribute my advocacy of the retention of the terms troostite and sorbite to my respect for the memory of the men in whose honor they were selected. In this he is mistaken.

I am fully aware of the desirability of distinguishing in our language between the constituents troostite and sorbite resulting from the transformation of austenite and between structures to which the same names have been given resulting from the reheating (tempering)

of martensite. I think, however, that this should be done with as little upsetting as possible in our present nomenclature — and in view of the fact that the terms have been used by several generations of students, it seems preferable to get over the difficulty by referring to the first group as "lamellar" and to the second as "granular." To attach to lamellar troostite and to lamellar sorbite the name of pearlite is open to serious objections.

<div align="right">ALBERT SAUVEUR
Professor Emeritus of Metallurgy
Harvard University</div>

"Kindred" and "Foreign" Nuclei

LEOBEN, *Germany* — It is becoming well accepted by metallurgists that all transformations in metallic systems (melting, solidification, allotropic transformations, precipitation of excess constituents) are influenced more or less by the action of nuclei. It may not be too much to say that the metallurgy of the future will concern itself with the smallest of additions, and their influence on the kind of inclusions normally present and the dispersion thereof.

In a series of researches undertaken by the writer aided by grants from the British Iron and Steel Institute (the results of which have been published in *Carnegie Scholarship Memoirs*) a clear distinction has been made between two kinds of nuclei:

1. "Kindred" nuclei (or intrinsic nuclei) are metallic lattice residues from the stable phases existing before the transformation. Such may include various addition elements or compounds thereof in copper-lead alloys for bearings, or undissolved carbides in steels reheated above the critical temperature.

2. "Foreign" nuclei are those usually called non-metallic inclusions. While there is some question as to whether carbides, nitrides and phosphides should be called non-metallic inclusions along with the usual oxides (see, for instance, the discussion of Mahin and Lee's paper in ⊕ *Transactions*, June 1935) most are agreed as to the great practical importance of the latter. It must also be emphasized that in most cases their effect depends inversely on their size; a veritable cloud of sub-microscopic particles ("slag clouds," as I have called them) have often a predominating effect.

Generally speaking, kindred nuclei encourage the formation of the particular lattice to which they themselves belong — they have a definite inoculating effect. This is also some-times caused by non-isomorphous materials, as pointed out by Portevin in METAL PROGRESS for January 1938, but the present writer believes that this effect is a comparatively weak one.

Consideration of available experimental facts makes it clear that every transformation may be influenced by *both* kinds of nuclei.

Take as an example the grain growth characteristics of a plain carbon steel of hypo-eutectoid composition, to which was added a little aluminum during the last of the refining period in the furnace. When such a steel, in the form of a hot rolled, annealed bar, is reheated to above the critical point, there can exist two kinds of kindred nuclei (traces of alpha iron — probably very few — and undissolved particles of carbide). Furthermore, there will be present a multitude of foreign nuclei, depending on the steel making practice, and these will include more or less pure oxide particles such as Al_2O_3, FeO, MnO and SiO_2, and simple and complex silicates and other mixtures of these oxides. This cloud of particles not only has an influence on the number of crystals of gamma iron which form (austenite grain size) but also on the "grain size" when it is cooled without heating much above the critical.

If the temperature rises higher into the region where gamma iron is stable, both kindred inclusions and the finest of the foreign inclusions will be dissolved in the gamma matrix. This reduction in the number of nuclei has a paramount influence on the grain growth characteristics of the austenite, and of course on the later transformations during cooling.

Considerable discussion has occurred in America, where the subject is given most importance, as to the specific action of aluminum, the element ordinarily relied upon to control grain size. It is my opinion that not enough is yet known to decide this point. Aluminum can exist in the steel as dissolved atoms of metal, or it can form alumina (Al_2O_3) either pure or joined with other oxides. The metal in solution may act as a stabilizer of an effective slag cloud, or influence the solubility of the carbides (or even of the foreign nuclei) in the austenite.

In any event, it is worth repeating that *both* kinds of nuclei, kindred and foreign, be considered when studying metallurgical transformations. Only in rare cases can it be established that only one kind is present, and then only under the most precisely controlled experimental conditions.

<div align="right">ROLAND MITSCHE
Professor, Leoben School of Mines</div>

By J. H. Loux
Salem Engineering Co.
Salem, Ohio

Automatic furnaces for

heat treating large

diesel parts

A COMPLETE heat treating equipment for hardening diesel engine cylinder heads made of aluminum alloy has recently been purchased by Machinoimport for shipment to the Soviet Union. A general drawing of the device as designed and built by Salem Engineering Co is shown on the next page. It consists of a hardening furnace, and an aging furnace, side by side and is arranged with electrical devices for automatic transfer of the material through the hardening furnace, the quenching operation, and the aging furnace.

As shown, the hardening furnace chamber is approximately 45 ft. long and 6 ft. 6 in. wide. The aluminum alloy castings or forgings are conveyed through the hardening furnace on two rows of trays. The aging furnace chamber has the same cross-sectional area, and is approximately 16 ft. long. The material is likewise conveyed through this furnace in two rows and on the same trays on which it entered the hardening furnace.

The furnaces have production capacity for approximately 320 lb. of aluminum alloy parts per hr., heated to a temperature of from 975 to 1110° F. (520 to 600° C.). The reason for the difference in the lengths of the furnaces is the different time required in the heating chambers; a long soak for solution treatment is followed by a relatively short aging at the proper temperature to precipitate the hardening constituents.

Production of 320 lb. per hr. is based on loading two diesel engine cylinder heads, weighing approximately 35 kg., on each tray, and four of these are delivered each hour, which means that two trays are introduced into the furnace at the charging end and two trays withdrawn from the discharge end each hour. Time in the hardening furnace is approximately 17 hr. Aging requires approximately 6 hr. at 600° F. (320° C.). Total time in process for cylinder head alloys is therefore 24 hr.

At the discharge end of the hardening furnace a combination spray and immersion quench is located. This provides for either type of cooling, depending on the metallurgical requirements. This auxiliary mechanism is also arranged for automatic operation.

After the operator in charge of the furnace has loaded a pair of trays in front of the pusher-head at the charging end of the hardening furnace, he does not even need to push a button, for all further operations are automatically controlled. He cannot hurry the metal through, for the time in the furnace is controlled by a timer set for predetermined intervals of operation — which in this case is approximately once every 60 min.

When the timer makes contact at the proper moment, the following operations occur in the sequence as described. All motions are interlocked, so that in case of failure of any part, the entire equipment comes to a stop.

1. Assuming the furnace is loaded with material, the first operation is to remove the two trays of heated alloy at the discharge end of the hardening furnace. The first contact of the timer actuates the mechanism which opens the discharge door of the hardening furnace.

When the door has reached the open position, it starts the mechanism for driving the rolls that propel the two trays nearest the discharge out onto the quench platform. When the trays are clear, they cause the door to close by making a contact, at which time the water in the spray quench is automatically turned on and the driven rolls in the hardening furnace come to rest. The charge may then be spray quenched or, if another setting is made, the trays and the quenching table will be submerged in the tank for a predetermined interval, ranging from 2 to 30 min.

2. When the discharge door is closed, the charging door of the furnace opens automatically and when fully open it actuates the pusher, and the two trays of fresh material are pushed into the heating chamber. At the same time all trays in the hardening furnace chamber are advanced 30 in. by being pushed ahead of the new trays coming in.

Furnace for Quenching and Aging Large Diesel Parts of Aluminum Alloy Is Completely Automatic. Operator merely needs to unload finished work, move empty tray to loading platform, and load empty tray. Capacity is about 4 tons per 24 hr.

3. When the pusher-head has reached its inmost position, contact is made causing it to return to its original position, when another contact closes the charging door. It will be noted that at no time are both doors open; this avoids undue cooling by cold drafts.

4. The two trays in the spray quench or in the submerged quench have, at the end of the predetermined quenching cycle, been automatically raised to the level of the cross pusher.

5. The cross pusher is then actuated, transferring trays to directly in front of the charging door of the aging furnace.

6. Trays reaching this point actuate a mechanism to open the charging door of the aging furnace. When this door has reached the open position, it makes a contact which starts a pusher and moves the two trays into the aging furnace.

7. When the pusher has reached its inmost position, it also makes a contact returning it to its original position, whereupon a contact closes the charging door.

8. As the two trays of quenched material

Plan

Sectional Elevation of Hardening Furnace
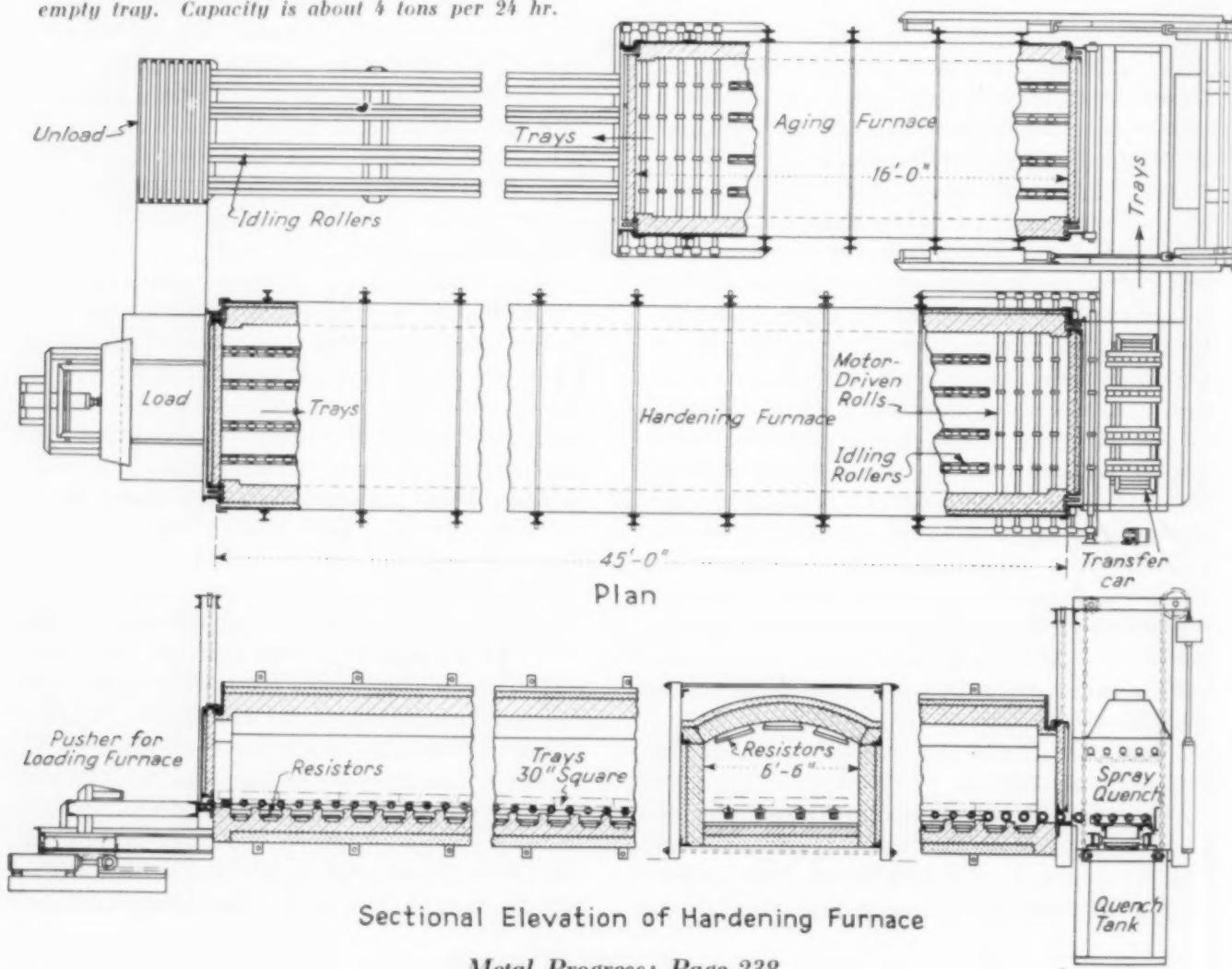
are propelled into the aging furnace, the trays already in this furnace are advanced 30 in. by being pushed ahead of the incoming material.

9. The aging furnace discharge door then opens and as it opens, it lowers the stop which holds the last two trays of material on the inclined outgoing discharge rollers.

10. Released trays of material then move down the gravity rollers, as indicated by "idling rollers" in the drawing, being stopped at a point adjacent to the charging end of the hardening furnace.

11. As the trays clear the discharge door, it automatically is closed by a contact made by the advancing tray.

Quenched and aged material is t h e n removed from these trays by the operator, who lifts the light trays to position in front of the pusher-head for the hardening furnace, and they are then ready to make another round trip.

Power input of the hardening furnace is a maximum of 150 kw., and that of the aging furnace is 40 kw. Both furnaces are of the resistance type and the heat is distributed through loops of alloy heating elements. These heating elements are cast of 35 nickel, 14 chromium, 50 iron. They provide a large area of heat distributing surface directed toward the charge in the furnace; the high grade alloy operating at a relatively low temperature will assure a long life.

Heating elements are hung from the furnace roof and laid between piers on the furnace bottom underneath the charge, thus providing a uniform source of heat from both above and below. Although it would have been easy to install fans in this equipment for circulating the hot air, the temperature of the hardening furnace (which may reach 1100° F. or 600° C.) is high enough to justify the use of radiation alone. Our experiments indicate that at approximately 800° F. the speed of heat transfer from resistor to work is approximately the same for convection heating and for radiation. Above this, radiation has a progressively greater advantage in speed of heating. Since the grids could be placed directly above and below the work and in view of the first cost of motor-fans and expense of operation and maintenance, the decision was made to heat by radiation alone, even in the aging furnace.

Heating elements in the hardening furnace are divided into three control zones. The first occupies a space of approximately 11 ft. adjacent to the charging end, and is powered with

62 kw. It is in this zone that much faster heating takes place, due to the cold material entering the furnace. The second zone occupies approximately 30 ft. of chamber length and is powered with 78 kw. The third zone is narrow — approximately 3 ft. near the discharge door — on account of the abnormal losses through the discharge door. This zone is powered with approximately 16 kw.

Each heating zone is automatically and separately controlled by means of a potentiometer type temperature controller which, in addition to keeping the temperature within any predetermined range, draws a record of the temperature so that a complete history of the heat treatment is available.

Electric current is supplied to the three zones by two Scott-connected transformers, arranged to take current from a 3-phase, 220-volt, 50-cycle line. Secondaries of the transformers are provided with the necessary variable voltage taps, to adjust the power input into the various zones and the whole furnace. In other words, if the furnace is being operated at 50% capacity, then by proper utilization of the radial switches, the power input can be adjusted to approximate the requirements of the furnace. This results in decreasing the power demand and permits the furnace to operate with a better load factor.

Current is supplied to the resistors at low voltage because of the large cross-section of the heating elements. One principle of design is that by providing a large area of surface for heat distribution there is no large temperature difference between the heating element and the work *when it is at temperature*. This assures closer uniformity than if resistors operated at a higher temperature. In other words, the distribution of heat within the furnace is a function of the area of heat distributing surface. Use of the specially shaped, cast sections provides five to six times more heat radiating surface directed toward the charge than can be obtained with ribbon resistors.

Operation of resistor furnace and its uniformity in output can be benefited if workmen in charge will carefully adjust the power input into the various zones to the actual heat requirements (as nearly as possible). For instance, if heating elements requiring only 50 kw. are subjected to a 100-kw. load, the element will get much hotter before the automatic control couple shuts it off, and there will be a considerable drift past the desired temperature. Further, the

waste of operating at overload is quite apparent, for it increases the demand, and power charges are calculated on the basis of demand or connected load. The higher the load factor and power factor, the lower the ultimate cost of power for the operation.

Resistance furnaces operate at a power factor of better than 95%, and full use of the switching equipment installed with such a unit as this one will improve the load factor and therefore lower the cost of heat.

These furnaces are enclosed in steel shells, amply reinforced by structural shapes, and are lined with light weight refractory firebrick. The hardening furnace is backed up with insulating brick.

The hearth of the hardening furnace consists of a series of cast roller rails made of 18-8 nickel-chromium steel. Other rails and rollers on the spray quench, transfer, aging furnace and extension table are of gray iron, they either being heated but moderately or not at all. Roller hearths reduce the force required to push trays through the furnace; therefore lighter trays may be used than though sliding friction had to be overcome under the string of loaded trays.

Trays themselves are very simply made of mild carbon steel. A piece of 3x3x⅜ in. angle is properly notched on one leg, bent into a 30-in. square rectangle and all joints welded. Across the bottom are welded two 3-in. channels, flanges down and flared slightly at ends to form the riding track. Four ¾x⅛-in. bars are then welded crosswise to form bottom slats, and the bottom then closed by a square piece of wire screen (0.192-in. wire, ⅝-in. mesh).

This type of tray will withstand the moderate temperatures in the hardening furnace, and can be readily repaired or replaced. It weighs 118 lb. The open construction allows the maximum area for radiation from the heating elements placed on the hearth of the furnace.

These furnaces have been located side by side to provide a common point for receipt and delivery of work. One workman can easily load and unload the furnace, return the trays to the hardening furnace, and still have the most of his time available for other duties.

As is the case with most modern production equipment, these furnaces are especially designed for one particular operation. The entire unit is an assemblage of well known methods for heating uniformly a n d automatically controlling the operation. This in turn assures uniform quality in the product.

Reflections on Rupture

By P. W. Bridgman

SINCE rupture of solid materials almost always follows the application of too great loads, we have acquired an instinctive feeling that the "cause" of the rupture is the application of an overpowering stress in a direction properly related to the plane of rupture. This intuitive concept is worthy of a critical analysis.

All through my high pressure experimenting I have been bothered by fractures that occurred during the release of pressure. I have also made many attempts to form coherent bodies by compressing powdered material in a die, and there are many substances which invariably fall apart, on removal of the mold, into disks, sometimes very thin, perpendicular to the axis. Such phenomena are similar to results of experiments by Griggs, who compressed a limestone block, at the same time submitting the mass to very high hydrostatic pressure. This induced considerable plastic flow in this ordinarily brittle material, and when the compressive load was released before failure and then the hydrostatic pressure released, the block would rupture into plates along planes perpendicular to the original direction of compression.

Now let us look a little more carefully at what is involved in the idea of a deformation under forces acting on a body, forces which lead to eventual rupture.

Under normal conditions, every atom in the solid is in a stable force field, that is, the net force called into play when that atom is displaced is in such a direction to restore it to its position of equilibrium. Now apply a compressive load in one direction. The body shortens in the direction of the load, because only in this way can the outer layer of atoms in the face on which the load acts receive from the next deeper layer of atoms the repulsive support necessary to balance the actions on the external face, and the next deeper layer from the next, and so on. But under this loading there is also a change in transverse spacing of atoms, which separate or approach depending on their mutual forces, whether attractive or repulsive.

Analysis indicates that there is no component of stress acting in the direction of this transverse change of dimensions, and this is important because it violates the intuitive demand for a stress component in the direction of movements to an eventual fracture — that is, for a stress which shall "make" the fracture occur.

Returning to the atomic movements in a body under load, the effect of an external force is to cause the atoms to find new

By Charles H. Herty, Jr.
Development & Research Dept.
Bethlehem Steel Co.

English steel making

in practice and

in theory

EIGHT groups of papers presented at the May 1938 meeting of the British Iron and Steel Institute cover steel making operations and steel making principles in great detail. There are six groups dealing with operations in different districts, one paper correlating openhearth data from numerous plants, and one paper on the application of physical chemistry to steel making. In each district-paper metallurgical considerations involving local problems are presented. Furnace operators and metallurgists would all do well to have a copy of the papers of this symposium, as there is a wealth of information regarding British openhearth and steel making practices.

The paper on the correlation of practice is full of valuable statistics. One of the most noteworthy points is the wide variation in characteristics of different plants. Furnaces range from 55 to 270 tons (basic) and 40 to 115 tons (acid) in capacity. Tons per hour range from 3.5 to 14.2 (basic) and 2.4 to 6.0 (acid). Fuel consumption falls between 355 and 590 lb. of coal per ton for basic (450 and 700 for acid) with producer gas being the predominant fuel.

Although the pig iron varies in composition in various districts, average compositions are shown at the bottom of the page. The unusually high phosphorus content of the basic iron results in high lime charges and large slag volumes. The limestone equivalent in the charge runs as high as 516 lb. per ton with a fair average being about 325 lb. Slag volumes are correspondingly high, ranging from 10 to 25%.

Such high lime charges and high slag volumes necessarily result in low tons per hour and high fuel in the basic process. Phosphorus, however, is utilized as a by-product, since the slag, containing from 6 to 17% P_2O_5, is used for fertilizer. Heats must be worked with a minimum of fluorspar, as this flux is detrimental to the citrate solubility of the slag, but fortunately the high phosphorus slags are quite fluid. The slag is gradually made limey to avoid too heavy a slag at any stage of the operations.

With the high phosphorus metal low silicon is important; therefore most mixers are "active" — that is, they are heated units used as preliminary work vessels wherein iron ore and lime are charged in order to eliminate silicon. Examples are 1.16% Si entering mixer, 0.50% leaving; 0.80% entering, 0.30% leaving; 0.72% entering, 0.32% leaving; 0.99% entering, 0.33% leaving. This enables a low silica slag to be carried in the openhearth and easy phosphorus elimination.

In each paper the importance of proper "pit-side" operations receives merited attention.

Steel Making Irons Used in England

ELEMENT	FOR BASIC STEEL	FOR ACID STEEL
Carbon	3.60	3.80
Manganese	1.00	0.40 to 2.00
Phosphorus	1.30	0.023 to 0.060
Sulphur	0.06	0.018 to 0.060
Silicon	0.60	2.20

Review of Symposium on Steel Making at May Meeting, British Iron & Steel Institute

Cleanliness is stressed time and again, and it is the general belief that a large number of ingot defects originate in poor pit practice. A great deal of work is being carried out on quality of refractories for bottom pouring, and ladle and nozzle brick.

Two definite opinions are expressed as to finishing conditions in acid openhearth steel: (1) The heat should be finished with a slag which allows silicon to be picked up from the slag and banks, and (2) the heat should be deoxidized with silicon and manganese. Discussion on these points is reminiscent of discussions before the ⊕.

Slag control is being studied carefully to determine its proper place in operations. The importance of the operator is stressed repeatedly but studies are reported in the symposium which show that much thought is being given to the fundamentals of slag control through a knowledge of the reactions occurring between slag and metal and in the slag itself. The proper way to form a slag is best illustrated by a delightful paragraph by R. Percival Smith in the report from the Sheffield District:

"Slag-forming makes great demands upon the furnaceman. When the charge is completely melted without a trace of solid residue, a further quantity of lime, the so-called 'feed lime,' is put in. The amount of feed lime added, calculated beforehand, is sufficient to suppress the action of the bath, and the first step in the forming of a slag has been taken. The melter must now play a waiting game; he must resist the temptation to rush the charge into premature action, to which happenings at neighboring furnaces will often incline him, and he must be able to protect his furnace from the dangers that are bound to present themselves when heat is being forced onto the surface of a liquid which is quite still or broken only by the bubbles from a very placid 'boil.' It is only when the feed lime has been thoroughly assimilated, assisted in the final stage of slag formation by small additions of spar spread as evenly as possible over the surface, that he may safely proceed to the next stage, the feeding of the furnace. Patience will, however, be amply rewarded. The furnaceman can now, and should, feed his furnace, not cautiously and hesitantly, but boldly. The stored heat of the bath permits resolute handling; the content of phosphorus and sulphur drops quickly to a low figure, and very soon the bath breaks out into an even boil and assumes a creamy appearance, very attractive to the eye."

Why can't we write like that?

Hay, Ferguson, and White (Glasgow District) go into considerable detail on the relation-

ships between FeO, Fe_2O_3, CaO and SiO_2 in the acid and basic processes. They conclude that calcium ferrites in basic, and ferrous silicates in acid slags control the states of oxidation of the iron oxide, and that when both CaO and SiO_2 are present, the tendency is to form calcium silicate which, in the case of acid steel, releases FeO and MnO with depletion of the slag in MnO and FeO and an increase in the manganese content of the metal. They believe that slag viscosity probably has a very marked effect on gas oxidation, but give no data on this subject. As a matter of fact, few practical methods are given of utilizing their observations.

Accurate Temperatures Needed

Temperature is stressed by Dawtry, Hatfield and Wright (Sheffield) as being of extreme importance, and they state that it is of the utmost importance to find a quick and accurate method of measurement. Work on this subject is being done by an Institute committee.

The most important question of the day, according to the Sheffield group, is "What is the actual oxygen content present during the working of the charge, and in what form does the oxygen exist?", and they believe that "until this question and many others have been adequately answered, steel making must be regarded as a very skillful process, dependent upon the adequate interpretation of practical observations in an empirical but effective manner."

An important paper by Andrew McCance on The Application of Physical Chemistry to Steel Making is divided into eight sections. In his introduction various physical and chemical constants and terms are defined. The most important of these, that of "activity," is emphasized because it has previously been shown by Chipman and others that the activity of an element is proportional to its concentration in dilute solutions. McCance shows, as in the first diagram on page 245, that when high metal concentrations are reached, the activity of the substances is not proportional to their concentrations, deviating to a wide degree.

The section on reduction of oxides by carbon deals with the distribution of iron oxide between slag and metal and with the reaction between carbon and iron oxide. In order to obtain volume percentages, McCance has introduced a correction term for the density of the various slag components, and to obtain the distribution ratio of FeO between slag and metal has arrived at the following equation:

$$\frac{\text{FeO in metal}}{\text{FeO in slag}} = 0.70 \times \frac{\text{solubility of FeO}}{100}$$

This gives consideration to the average difference in density of either silicate or lime slags, but, of course, does not take into account the association of FeO with other slag constituents.

The equilibrium constant for the reaction $C + FeO = CO + Fe$ has been determined under openhearth conditions and in the laboratory by various investigators. In this connection, McCance believes that Schenck's theory of polymerization of carbon is unwarranted and he arrives at the value

$$\text{Log } K = -\frac{6230}{T} + 5.246$$

for the equation $[C] \times [FeO] = K$ at various temperatures.

McCance states that the iron oxide in the metal depends upon the rate of carbon elimination, but it appears to this reviewer that he has fallen into the same error as some other writers in putting the cart before the horse, for the rate of carbon elimination should depend upon the carbon concentration and the FeO in the steel.

A great deal of space is given to details of the manganese reaction. This is unquestionably the most studied reaction in steel making and McCance uses it to bring out the differences between acid and basic slags. He shows that the constant

$$K_{Mn} = 100 \frac{(\% \text{ MnO in slag})}{(\% \text{ FeO in slag}) \times [\% \text{ Mn in metal}]}$$

is 245 for basic and 1250 for acid slags at refining temperatures. The difference is attributed to combination of MnO and SiO_2 in acid slags (actually the difference is due to combinations of *both* FeO and MnO with SiO_2), the higher constant for the acid slag showing the great association of MnO with SiO_2 in the form of silicates, and thus the ease of reducing manganese from a basic compared with an acid slag.

Of all the constants which have been arrived at for the silicon reaction McCance prefers the equivalent constant of Körber and Oelsen which for silicon and iron oxide in solution in the metal is

$K'_{Si} = [Si] \times [FeO]^2 = 7.1 \times 10^{-4}$ at 1600° C.

In order to use this constant where the oxidation of the slag may be taken into account, he has arrived at a constant for the acid openhearth,

$K''_{Si} = [Si] \times (FeO)^2 = 8.44$ at 1600° C.

where (FeO) is the concentration of FeO in the slag. When lime is added to an acid slag it increases the silicon in the metal by temporarily releasing MnO and FeO which react with carbon in the iron, lowering the content of FeO in the slag and thus raising the silicon content of the metal. Cleanest steel is produced in this way by direct reduction of silica from slag or bottom,

but to get this the bottom must always be in good shape.

McCance lays great stress on the reaction

$$2\,MnO + Si \rightleftarrows SiO_2 + 2\,Mn$$

and indicates how its equilibrium is disturbed by phosphorus, sulphur, nickel, cobalt, copper, chromium and aluminum to the metal and by CaO, Al_2O_3 or TiO_2 to the slag. "If a steel contains more manganese than equilibrium conditions require" to quote his words, "then this excess manganese will reduce the silica of the refractory material with which it is in contact in an endeavor to attain equilibrium. In other words, the refractory material will be attacked," and, he might have added, giving rise to dirty steel. "The same reasoning applies to other deoxidizers, and since, for a given manganese content, a very small proportion of aluminum is sufficient to maintain equilibrium, the converse is also true — that is, a small aluminum content in the steel is sufficient to prevent the refractory from attack. The importance of this on the technique of bottom running is not yet generally realized."

Sulphur Elimination

A detailed review of the sulphur reactions is also given by Dr. McCance. High sulphur coal results in a pick-up in sulphur in the scrap and in the slag. "It is probable that two reactions proceed simultaneously:

$$3\,Fe + SO_2 = FeS + 2\,FeO$$
$$10\,FeO + SO_2 = FeS + 3\,Fe_3O_4$$

Both reactions are exothermic and so the equilibrium condition will result in less sulphur in the scale at high temperatures than at low. The most that can be said, therefore, is that with quick, hot melting the sulphur pick-up will be diminished."

Sulphur elimination in the openhearth bath is due to reaction

$$FeS + CaO \rightleftarrows FeO + CaS$$

electric furnace desulphurization being due primarily to the low FeO (and MnO) content of the basic slag. The distribution ratio between sulphur in the slag and sulphur in the metal increases with the CaO content of the slag, being 3 or 4 in the first or oxidizing slag, and 25 to 50 in the second or reducing slag.

When dealing with high sulphur irons, desulphurizing with manganese in the mixer is of great help. For mixer type slags K = [Mn] [S] = 0.07 to 0.09. For more concentrated

slags the constant increases rapidly, showing that the reaction is not as simple as was originally thought. From German work McCance gives the following table for the percentage of sulphur present in a sulphide inclusion as FeS for three temperatures and various manganese contents for a steel containing 0.06% sulphur:

MANGANESE IN STEEL	PERCENTAGE OF FeS IN INCLUSIONS AT		
	1600° C.	1500° C.	900° C.
0.10%	97.4	96.2	34.1
0.25%	93.8	91.2	17.2
0.50%	88.1	83.7	9.3
1.0%	78.8	72.1	4.9
2.0%	64.9	56.3	2.5

As the temperature falls, therefore, the proportion of the sulphur combined with iron in sulphide inclusion decreases, and the proportion of sulphur combined with manganese increases. According to McCance, this conversion goes on even in the solid state, and the change from a sulphide rich in FeS existing in liquid steel to a sulphide rich in MnS existing in solid steel will depend on the rate of cooling.

McCance believes that most of the trouble in rolling due to ingot cracking arises from the fact that too much iron sulphide is present between the crystals in the ingot. As an adjunct to the above table, he states that the percentage of FeS increases with the oxidation of the metal and that one of the functions of an increase in the manganese is to decrease the FeO content of the steel and thus decrease the FeS. The last diagram on the data sheet, page 245, shows the relationship between the percentage of sulphur as FeS, the oxygen content of the steel, the manganese content of the steel and red shortness. Proper rations of manganese to sulphur, together with the proper degree of deoxidation, should therefore prevent ingot cracking, or at least that part due to FeS. In this connection the present reviewer would say that the high FeO contents as shown by McCance are seldom found except in very low carbon rimmed steels.

Phosphorus is shown to be lowered by high CaO, high FeO, low P_2O_5 and low temperature. A dephosphorizing factor

$$F_P = \frac{1}{P} \times \frac{P_2O_5}{(P_2O_5 + FeO)}$$

when combined with the total CaO content of the slag enables one to determine quite accurately the requirements of the slag, or charge, for the desired phosphorus elimination. High manganese pig iron tends to retard dephosphorization because resultant high MnO lowers the effective CaO content of the slag.

Some Openhearth Reactions

Diagrams selected from "The Application of Physical Chemistry to Steel Making" by Andrew McCance, British Iron & Steel Institute, May meeting, 1938
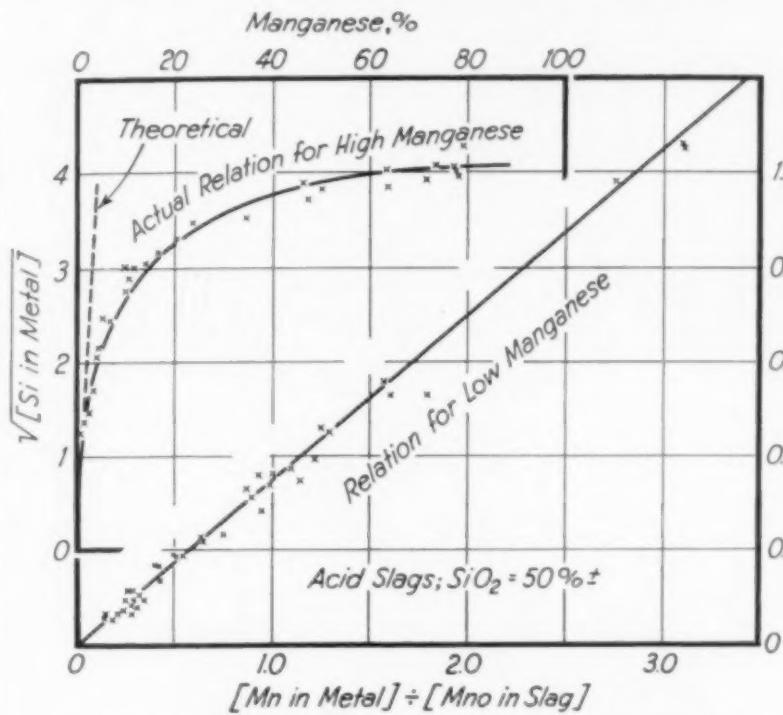
Reduction of Manganese and Silicon From Acid Slag Follows the Mass Action Law for Low Concentrations, but Deviates From It Widely at High Concentrations (Körber and Oelson)
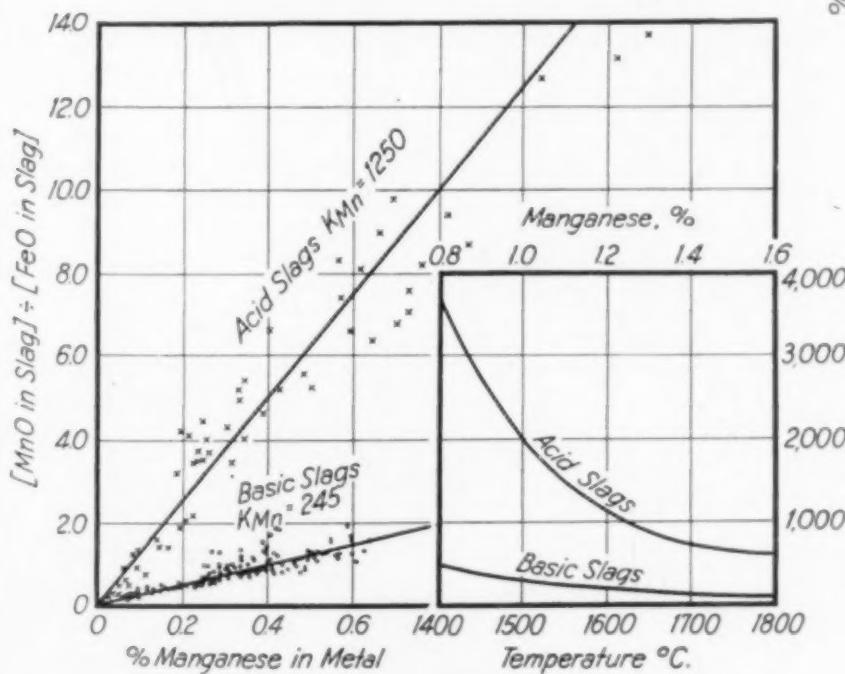

Manganese Is More Easily Reduced From a Basic Slag With Very High Lime Than From Acid Slags, Which Hold the Metal Oxides as Silicates (McCance). Inset (after Körber and Oelsen) shows that superheating changes the manganese equilibrium of a basic melt but slightly
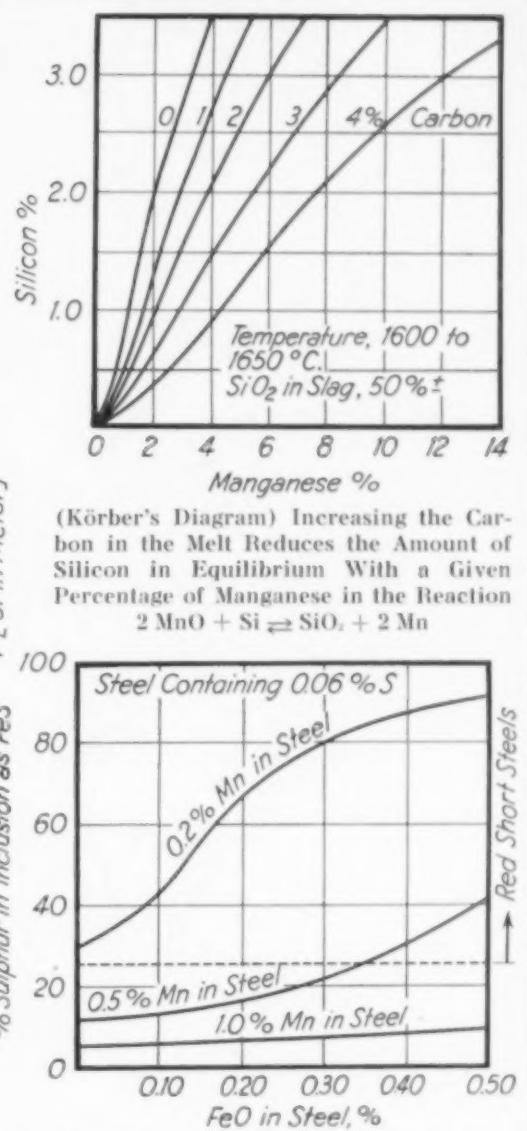
(Körber's Diagram) Increasing the Carbon in the Melt Reduces the Amount of Silicon in Equilibrium With a Given Percentage of Manganese in the Reaction
$$2\,MnO + Si \rightleftarrows SiO_2 + 2\,Mn$$
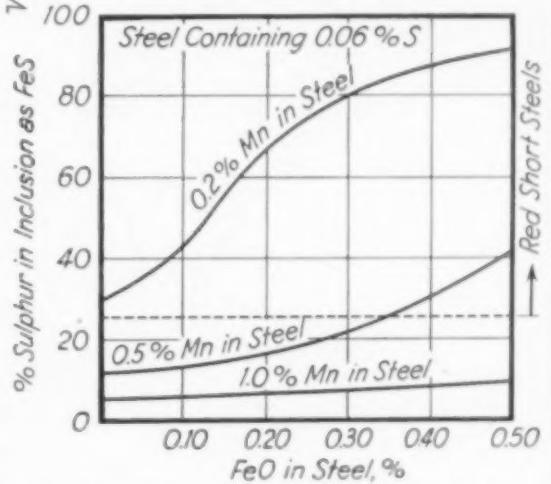
Compositions of Sulphide Inclusions (Fe·Mn)S Depends on the Manganese in Steel But Also on FeO in Steel. Conditions above dotted line make for cracked ingots due to red shortness (McCance)
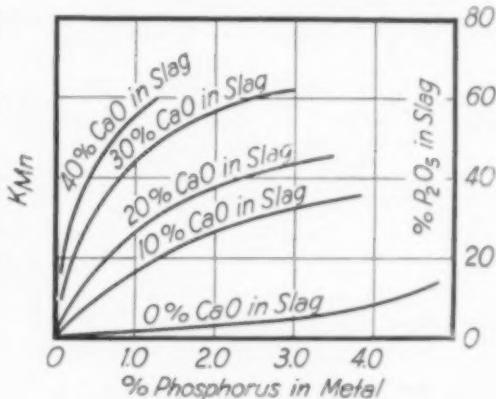
Lime Is the Most Active Substance Affecting Partition of Phosphorus Between Metal and Slag (Krings and Schackmann), but Action Is Indirect, Since FeO Is Probably the Principal Reactant:
$$2\,P + 5\,FeO \rightleftarrows 5\,Fe + P_2O_5$$

Plowing Corn...

...Digging Rocks

Opening new markets for farm tractors, Allis-Chalmers designed this new Model B. With 9 HP drawbar pull, this tractor offers mobile, economical power for many industrial uses. Despite the moderate cost of this tractor, more than a dozen highly stressed parts are forged from long-wearing Nickel alloy steels.

...or Damming Rivers

Digging rock for a cement mill, this big shovel keeps down tonnage costs. Big shovels, working at a big-yardage pace, need the extra strength and wear resistance of Nickel alloy steels. Bucyrus-Erie engineers developed a special Nickel alloy steel, similar to SAE 3135, and special heat treatments to achieve higher physical properties.

Hard jobs Call for Toughness

Grand Coulee, three times bigger than Boulder Dam, is being built with hoists which speed materials 550 feet aloft. Hoisting machinery is safeguarded by the extra strength of Nickel alloy steels. Paradox gates which plug the Columbia River, hold raging water and resist abrading silt, are made of Nickel alloy steels with tensile strengths from 80,000 to 110,000 p.s.i.

ALLOY **NICKEL** STEELS

Your consultation regarding the uses of Nickel is invited.

THE INTERNATIONAL NICKEL COMPANY, INC., NEW YORK, N.Y.

By Waldemar Naujoks
Chief Engineer
The Steel Improvement & Forge Co.
Cleveland, Ohio

Forgings for aircraft, manufacture and inspection

DIE PRODUCTION FORGINGS, as they are known today and including the drop forging, the upset forging and the press forging, had their real birth or beginning about 40 years ago, and have grown in importance with the automotive industry. Today they are a part of nearly every type of mechanical unit of metal. Reasons for their use may be several, depending upon which of the needs the forging may supply.

Die production forgings may be divided into about four general classes of quality, the quality for any particular class being balanced by the price factor. These four classes are (1) the "garden variety" or low priced forging, (2) the "commercial quality" forging, (3) the "special quality" forging, and (4) the "aircraft quality" forging.

The low priced grade is sometimes called the "garden variety" forging. Price is the all-important factor. The steel used may be mill off-heats as to chemical composition or physical condition, or even steel of re-rolling quality. Surface defects, pipes and cold shuts are of small consequence. Chemical defects, as carbon segregation or high impurity content, can be overlooked. Forging defects such as mismatched dies, cold shuts, overheated forgings, poor trimming, worn dies, and rough scaly surfaces are of little importance.

Yet, for many purposes forgings of this nature serve their purpose well, and any additional quality is not necessary. Cheap household vises, wedges, wrenches, clamps, pinch-bars, filler blocks, and such articles that have sufficient bulk to offset the defects may not require anything more exacting. The cheap chisel that the amateur mechanic uses once or twice a year may serve him just as well as the high quality tool that daily serves the mechanic.

Most die production forging falls into the class of "commercial forging." Steel must be of "forging quality," conforming to S.A.E. specifications for chemical composition; dies are maintained to a reasonable degree; workmanship is of a good grade; commercial tolerances are met in size, shape, surface condition and physical structure. Such forgings present a fine, workmanlike quality, and find extensive use throughout the metal industry where strength and dependability are required.

The "special quality" forging is a step above the commercial grade. Increase in quality may be due to closer chemical tolerances in the analysis, smaller than normal dimensional tolerances, better than average surface conditions, closer weight range, specified size for micro-grain, or a combination of tolerances in a closer than normal expectation. Forgings of this nature necessitate equipment in better than average condition, temperature control on forging and heat treating furnaces and highly skilled die sinkers and hammermen. Their production is coupled with a continuous and careful inspection of the product throughout each of the processing steps.

Forgings of special quality are used for the more severe conditions in industry, such as

parts to resist heat, pressure, shock, vibration, abrasion, or a combination of conditions where failure may prove expensive or dangerous.

The aircraft industry has demanded a still better classification in the gradation of forgings, known as "aircraft quality." Due to the highly restrictive conditions imposed upon the forged parts and the exacting tests imposed, only the cream of "special quality" forgings are acceptable. The several reasons for absolute flaw-free forged parts in the airplane will be discussed in what follows.

practices, which considered the production problems and followed the accepted requirements of the forging industry, were moved aside. Strengths that were obtainable only in isolated laboratory tests became production requirements. Flaw-free conditions obtainable only in a small percentage of forgings were demanded for all aircraft forgings. The aircraft designer incorporated into his shapes all factors that tended to make the forgings difficult and markedly promoted all the various forging defects, such as extremely thin sec-

Long Slender Forgings Require Close Heat Control. Slight variation in finishing temperature would tend toward rejections because of size tolerance. Length 18 in., spread 10 in., thickness varies from ¼-in. in I-beam channel to 2¼ in. at boss. Weight 14 lb. Chromium-nickel-molybdenum steel, (S.A.E. 4345)

Design for Aircraft Service

It is generally recognized by those familiar with the aircraft industry, even without the detailed technical knowledge and broad experience of specialists, that the two demands on all aircraft parts are weight and perfect dependability, and that these demands are insisted upon almost to the nth degree. Weight must be reduced to an irreducible minimum, yet not at the sacrifice of sufficient strength for safety. Due to the many uncalculable conditions encountered in service, it is also necessary to design for a sufficient reserve to handle the unknown forces, as well as to carry all of the known loads. To incorporate greater strength into smaller sections, it has been necessary for the aircraft designer to specify stronger materials, better workmanship, and more reliable products than have been heretofore considered satisfactory in other exacting services. Previous

tions, deep pockets, abrupt section changes, difficult locks, small radii and sharp corners. He further added to the difficulty by imposing close dimensional, physical and structural tolerances, often closer than have been previously considered acceptable by the users. In short, more is demanded in high physical qualities and flaw-free conditions in the aircraft forging than has been required in previous quality forgings, primarily because no excess metal can be put into the design to compensate for any slight deviation of strength in the part due to flaws or defects it might contain.

This "aircraft quality" has not materialized over night, but the quality of forgings for this service has been developed to a degree far beyond the seeming possibilities of a few years ago. Since steel is one of the important basic metals, certain necessary and rigid specifications are imposed upon all steels used for this purpose. It is evident that no forging can be

any better than the material from which it is made and the specifications assure the finest product of the steel maker's skill.

Adoption of magnetic tests for soundness, such as the magnaflux test, together with the more numerous and exacting tests on the bars themselves before acceptance, requires steel that is as free from all minute cracks and broken fibers as human ingenuity can make it. Specifications for the chemical composition and tensile strength do not differ greatly from those given in the standard commercial specifications. A comparison between three representative specifications will indicate this point. The American Society for Testing Materials specification represents good commercial practice. The U. S. Army specification represents ordnance requirements, and the U. S. Navy specification represents present day requirements in aircraft steels. Both the chemical composition and the tensile requirements in the three specifications are similar, with the usual ten point range in carbon content and maximum of impurities such as sulphur and phosphorus.

Specifications for Commercial, Ordnance and Aircraft Steels

	A.S.T.M S.A.E. X-4130	ARMY ORDNANCE WD-4135	NAVY AIRCRAFT X-4130
Carbon	0.25 to 0.35	0.30 to 0.40	0.25 to 0.35
Manganese	0.40 to 0.60	0.40 to 0.70	0.40 to 0.60
Phosphorus	0.04 max.	0.04 max.	0.04 max.
Sulphur	0.05 max.	0.045 max.	0.045 max.
Chromium	0.80 to 1.10	0.80 to 1.10	0.80 to 1.10
Molybdenum	0.15 to 0.25	0.25 to 0.40	0.15 to 0.25

Minimum Tensile Requirements

	A.S.T.M	ARMY ORDNANCE	NAVY AIRCRAFT
Tensile strength	125,000 psi.	120,000 psi.	125,000 psi.
Yield point	105,000 psi.	105,000 psi.	100,000 psi.
Elongation in 2 in.	16%	14%	18%
Reduction of area	50%	40%	50%

Similarity ceases with the number and types of tests necessary for inspection. For chemical tests the A.S.T.M. asks an analysis from each melt. The Army specifies samples from not less than 1% nor more than 2% of the number of bars in any one lot. Navy aircraft desires, where practical, samples directly from the top and the bottom of each ingot, but otherwise samples may be taken from broken physical test specimens.

Requirements for macro and micro etch tests also vary with the specification. A.S.T.M. requires a sufficient discard from each ingot to secure "freedom from injurious piping and undue segregation" and requires that the forgings shall be free from injurious defects and

have a workmanlike finish. Since no provision is stated for specific macro and micro examinations, they are usually not made. Forging quality steel is given suitable tests and inspections at the mill, which include visual inspection for seams and pipes, and macro etch inspection of samples from each heat for segregation.

The Army commercial specification states that the bars shall be subject to a macro etch test *when specified* in the contract or purchase order, and under visual examination shall show no evidence of segregation or abnormal change in structure from the surface to the center.

Navy aircraft specification states that at least one tension and one deep etch specimen is required from each 500 lb. of bars. This increase in the number of tests required and their severity, has resulted in many changes from the ordinary commercial steel mill practice. To the regular base price and normal extras is added another substantial extra for aircraft quality, to cover the increased number of tests necessary at the mill and the lower ingot yield. For the general practice, the ingot yield runs about 70% to 85%, but for aircraft steels this yield is reduced to about 50% to 75%.

Orders for aircraft steels are not accepted unless they specify electric furnace steel. The present practice is to take samples from each ingot and forge them down to the size of bars required; tests are then made on these samples to determine whether the ingots are of sufficient quality to pass the necessary requirements. If the macro and micro acid etch tests indicate suitable steel, the ingots are rolled to the required bar size. Samples are then taken *from each bar* for another searching examination of macrostructure and microstructure. Any evidence of the slightest crack or broken fiber will result in the rejection of the bar.

Forging the Aircraft Part

Forging practice for aircraft parts is, in many instances, a radical departure from the previously accepted forging methods, due primarily to thin sections and abrupt changes of section. The various forging steps which serve as preparatory operations in the dies in shaping hot plastic metal for the finishing impression must be worked out very carefully. The flow of metal must be guided at every step so as to protect the continuity of the fiber or grain structure. If the break-down operations are too severe, ruptured metal is the result. It is not

sufficient to avoid the more common defects such as scale pits, cold shuts, laps, seams, overheated metal, metal forged at too low a temperature, and unfilled sections; rather, it is mandatory that every precaution is taken to assure proper grain flow and correct metal distribution. The success in the forging operation therefore depends to a large extent upon the foresight and care exercised in the design and machining of the dies.

A second factor is the control of temperature. A portion of this rests in the provisions made for temperature control in the heating furnaces, and the balance rests in the skill of the hammer operating crew.

The eyes of even the most skilled and conscientious heater cannot compete in accuracy, day in and day out, with the modern temperature control systems. There was a time when such systems were expensive and ofttimes unreliable, but this is not true today. The initial cost still involves a considerable outlay, but when it is considered that no consistent, commercially accurate and proper grain refinement can be obtained without accurate temperatures, such a system becomes essential for aircraft forgings.

Most continuous types of furnaces are equipped with suitable pyrometric control so that the metal is brought up to the most suitable forging temperature at the most suitable rate. However, for the smaller sizes the batch type of heating furnace is still considered most economical. This type can also be equipped with proper temperature controls, but it is still necessary to depend upon the skill of the heater. In the modern continuous furnace, the cold stock is placed in the furnace and the heating cycle consists in moving the stock from one end of the furnace to the other, or completing a revolution in the rotary type. Completion of the heating cycle is assurance that the stock has

been heated to the proper temperature in the desired length of time.

However, in the batch type furnace, the stock is placed in the furnace somewhat hotter than the stock is to be treated, where it remains until removed by the heater. Should he remove it before it has been properly heated throughout its cross-section, the metal cannot flow freely in the forging operation; this may result in a defective forging and generally in a poor one, certainly too poor for aircraft quality.

Improperly heated stock can rapidly wear
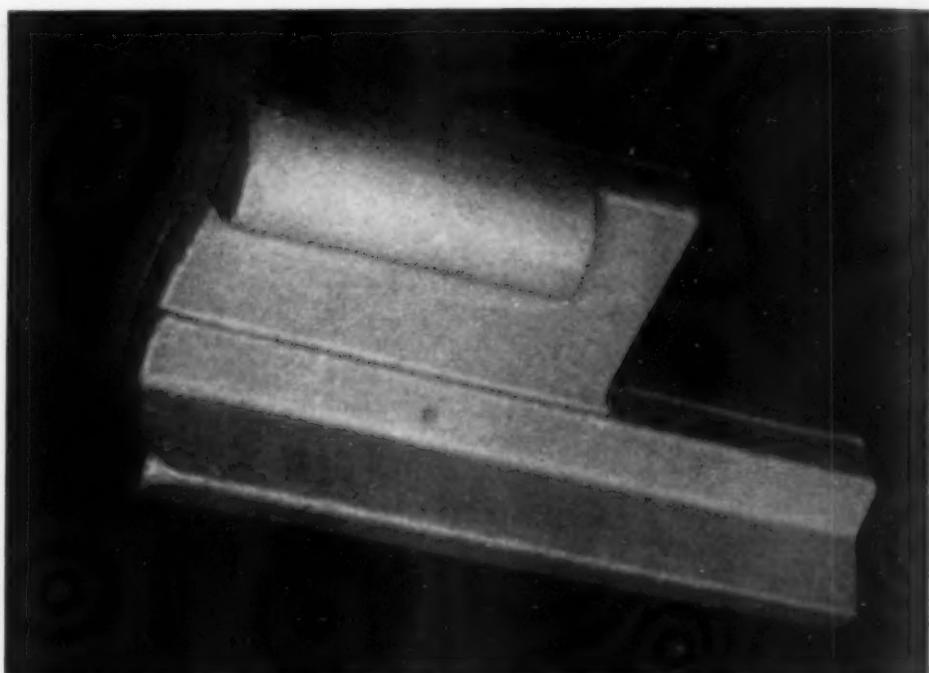
A Desirable Chunky Forging, Weighing About 9 Lb. However, the 19-9 type of stainless steel requires close temperature control and careful handling

the dies, which makes it difficult to maintain proper dimensions. On the other hand, the piece can remain in the furnace too long, which tends to produce a coarse grain structure which is not always removed or restored by subsequent forging and heat treatment.

The steel maker has put into aircraft quality steel all the skill and experience at his command and this exceptionally high quality steel can be either improved by correct heating and forging operations, or it can be ruined by improper procedure. Heating is one of the very important steps in producing a forging of superfine quality.

The third factor in forging rests entirely upon the skill and experience of the hammer operator and his crew.

On a new set of dies, the hammer operator

is not only concerned with filling the finishing impression, but he must watch very carefully the movement of the metal as it changes its shape from the bar stock into the shape of the finished forging. He must not only avoid the ordinary possibilities such as cold shuts, laps and unfilled sections, but the flow of the stock must be such as to avoid folded or irregular fiber structure, ruptured fibers, or a weak grain structure. These weaknesses are not always readily seen but, nevertheless, tend to impart debilities that must be avoided.

to take good metal and improve it by the proper heating and forging operation.

One of the important subsequent operations is trimming. Where the forgings are to be cold trimmed, it must be certain that this does not impart a perimeter crack around the trimmed part, caused by secondary shearing. Such cracks are very slight and barely discernible, but the release of the shearing strains in subsequent heat treating operations may cause further cracking. The best practice is to hot trim all forgings for aircraft service. Similar cracks
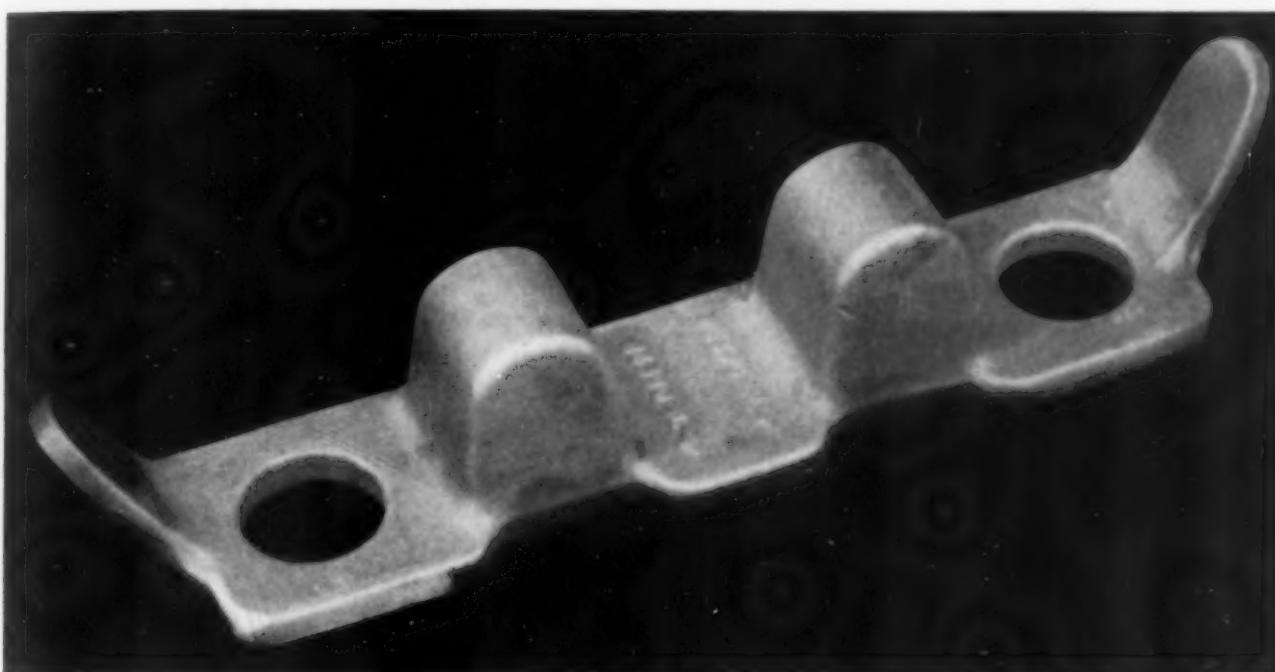
Alternate Thin and Bulky Sections on a Small Forging Weighing About 2 Lb. Length 8 in., width 1¾ in., thin sections 0.28 in. thick. Aircraft forging of X-4130 steel

It is the practice in some forge shops specializing in aircraft forgings to require several experienced men, such as the forge foreman, the superintendent, and the chief inspector, to be present during the start of a new set of dies so that any irregularities in the forging steps may be detected. Where weaknesses appear that are due to faulty die construction, suitable changes are immediately made in the dies; where the forging technique does not appear suitable for the part, that technique is changed. The size of the forging unit, the heft of each forging blow, and the temperature of the metal being forged must be carefully watched, so that when the finished piece is laid down for the further processing, such as trimming, punching, or heat treating, it carries with it the best traditions of the forging art, namely,

can be developed in punching operations. Proper clearances in both the trimming and the punching tools are essential.

The forged parts may be made of various grades of steel, either in carbon or alloy grades, but the important pieces are usually of an alloy steel that requires a heat treatment to develop the full physical properties. Where the part requires extensive machining, it is customary to normalize the forgings so that uniform machining conditions are obtainable throughout the piece. This also improves the structure for any subsequent quenching and tempering operations. At times faulty or broken fiber structures will appear during heat treating, but cracks may also be caused by faulty heat treatment. Particularly can this be true where the forging consists of alternate thin and heavy sec-

tions, or on a forging containing fairly sharp corners and small fillets.

Inspection during every step of the productive operations is a prime requisite. It was seen that the forging stock received thorough inspection during the steel making processes, and the inspection throughout the forging shop operations is required to be just as frequent and just as thorough. Forging stock is closely inspected for any visible defects, its chemical composition is carefully checked in the plant laboratory, and bar samples are deep etched to inspect surface conditions and cross-section porosity. After the bars have been cut into forging lengths, particularly if they are cut by cold shearing, the pieces are again carefully inspected to make certain that the cutting process has not developed shear or cutting cracks. Usually several of the first forgings are deep etched or magnaflux tested. After each step in production, the forgings are closely scrutinized to guard against any flaws that may have been overlooked in the preceding operations. Inspection for dimensions must be made in the same thorough manner. Often each forging is given a special etching pickle to study the surface condition. Any indication of the slightest fine line, a tendency towards a cold shut, or any other condition that appears doubtful in the least, is sufficient cause for rejection.

Forgings for army or navy airplanes must be inspected by an army or navy inspector. For military planes, all parts fabricated must be made in shops approved by the governmental aircraft departments, and this approval is not obtained until the plant has been duly inspected. These inspectors satisfy themselves that the particular forging shop has the necessary equipment and engineering facilities to produce forgings of the quality desired, and that these facilities will be employed when their forgings are being produced. No army or navy aircraft forging can be shipped until it has the inspector's stamp of approval, but this does not indicate that the forgings will be finally accepted by the aircraft builder or by the military inspector at that plant. During machining, heat treating, and assembling, the inspections continue, to insure that each part is in as perfect a condition as it is humanly possible to obtain.

The Price of Quality

It is generally conceded that the primary requisite in the aircraft forging is "highest quality," and nothing short of that will suffice.

However, the question is often raised, and fairly so, "Just what is the real value of the precautions and tests exercised in the processing steps of aircraft forgings, since these additional inspections tend to increase the cost out of proportion with other high quality forgings, such as automotive forgings?" It is known that forgings in the modern automobile are of remarkable quality, many of them being fabricated out of various grades of alloy steel, and that the automotive inspection is quite rigid. Yet to produce a quality product the automotive industry does not find it necessary to use these extreme precautions.

The first reason is that the design of the aircraft forging is generally such that the least weakness in the metal or in the forging processes will tend to promote these weaknesses to a much greater degree than in the relatively heavier sectioned automotive forgings. Even though many of the defects found in the earlier inspections might later be found after the aircraft part has been machined, these machining operations are much more expensive than the automotive because the small quantities do not permit the development and use of special machines.

The first reason is that the design of the aircraft forging is generally such that the least the automotive forging because of the greater permissible factor of safety which the heavier sections allow. Were it necessary for the automobile manufacturer to build a machine of the present power and strength, but to reduce the weight of the car one half, he would be faced with about the same problem that the aircraft builder meets.

Reduction of weight without the sacrifice of strength has changed to a marked degree the technique of the forging plant that serves the aircraft industry. "Aircraft quality" is the peak in the grades of forging qualities. Just as the various grades of diamonds can be used to best advantage for their several purposes, from the blemished diamond which can true the grinding wheel to the flawless stone for a queen's crown, the various grades of die production forgings have their niche in serving mankind in various capacities.

Progress of man's mastery over the air depends entirely upon his ability to produce a craft without one weak link, and in striving for components without flaws and without weaknesses, the forger of aircraft forgings needs all of his engineering ability and his forging art.
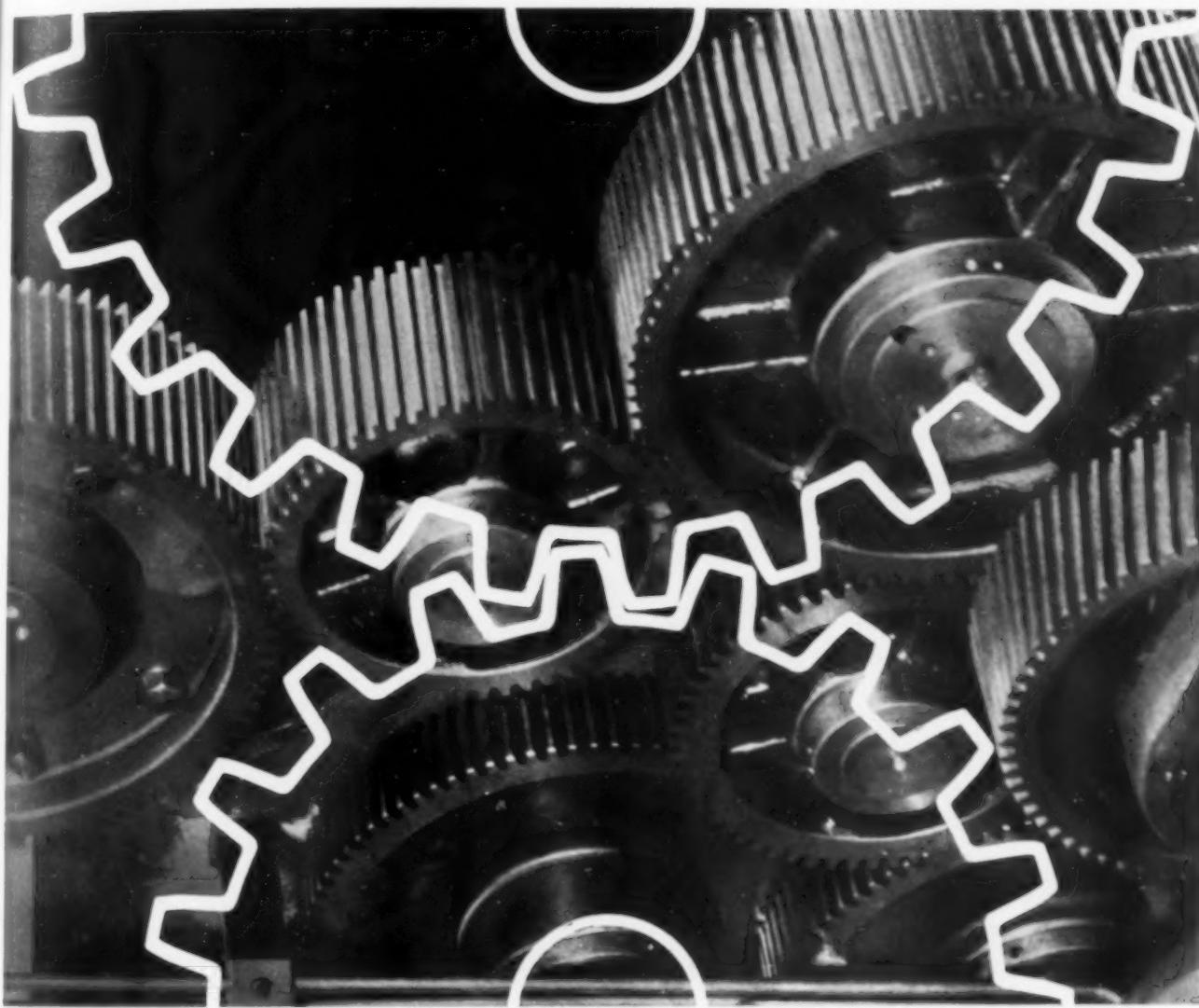
PRECISION GEARS AT LOW COST

THE quality of the gears in a high-grade machine tool determines its performance.

One well-known machine-tool builder finds 0.35% Moly Chrome-Molybdenum iron meeting all requirements for main and intermediate gears in an automatic crankshaft lathe. The iron is wear-resistant enough to assure maintenance of original tooth profiles, thus eliminating tool chatter. Its structure — and therefore its strength — is uniform. There is no trouble from porosity at the bases of the gear teeth. This Chrome-Moly iron also holds down production costs. It is comparatively inexpensive. It machines easily. And in the case referred to above there has never been any waste from defective castings since it has been adopted.

If resistance to wear, uniform strength, plus economical production are vital requisites in the gears, pulleys or similar machine parts you make or use, investigate Moly irons. Our book, *"Molybdenum in Cast Iron,"* is free to engineers and production executives. Climax Molybdenum Company, 500 Fifth Avenue, New York City.

PRODUCERS OF FERRO-MOLYBDENUM, CALCIUM MOLYBDATE AND MOLYBDENUM TRIOXIDE

MOLY

Climax Mo-lyb-den-um Company

September, 1938; Page 253

Personals

William B. Scott ⊕ has left Detroit Electric Furnace Co. to become engineer for the Chemicals and Pigment Division of the Glidden Co. at Collinsville, Ill.

Now employed by Allis-Chalmers Mfg. Co., Milwaukee: William R. Parks ⊕ as engineering apprentice.

Louis J. Larson ⊕, for many years director of welding research for A. O. Smith Corp., Milwaukee, has resigned to enter consulting work on welding problems.

Gordon McMillin ⊕, formerly with the Buckeye Traction Ditcher Co., has been appointed chief metallurgist for the Standard Brake Shoe and Foundry Co. of Pine Bluff, Ark., and Memphis, Tenn.

George Ellerton, Jr. ⊕ has joined Faville-LeVally Corp., Chicago, as sales engineer.

Eugene Schmidt ⊕ is now with Indiana Steel Products Co., Valparaiso, Ind., as chief chemist and metallurgist.

E. W. Goodaire ⊕ has formed the Ring-Free Oil Co. of Cleveland to warehouse and distribute wholesale the products of Macmillan Petroleum Corp.

Now chemist in research laboratory of Columbia Chemical Division of Pittsburgh Plate Glass Co., Barberton, Ohio: William A. Franta ⊕, formerly sales engineer with Superior Steel Corp.

Harry O. Munn ⊕, formerly chief service engineer for Lindberg Engineering Co., has been placed in charge of a new office in Buffalo, for western New York.

George H. Morel ⊕, M.I.T. June 1938, is now employed by Builders' Iron Foundry of Providence, R. I., starting a one-year training course in foundry engineering.

Traveling to Peru: Frank E. Noe ⊕, on a three-year contract with the Cerro de Pasco Copper Corp. as a junior metallurgist.

Transferred to St. Louis by Climax Molybdenum Co.: H. E. Hostetter ⊕, as metallurgical engineer of the new St. Louis office.

Allan G. Shepherd, Jr. ⊕, formerly materials engineer for Hancock Valve Co., Boston, is now metallurgist for Taft-Peirce Mfg. Co. of Woonsocket, R. I.

Awarded an honorary membership in the American Society for Testing Materials: F. O. Clements ⊕, technical director, Research Laboratories of General Motors.

Carl B. Rex ⊕ has recently been appointed metallurgist for the U. S. Naval Torpedo Station at Newport, R. I.

Efficiency of the Blast Furnace

(Continued from page 221) rich in CO to effect the required reduction of Fe_3O_4 to FeO in the second chamber, and its effluent will effect easily the reduction of Fe_2O_3 to Fe_3O_4 in the first, the final exhaust having $46\frac{1}{2}\%$ CO (representing 623 lb. of the original carbon which must be carried for "potential" or driving force for the reaction) and $53\frac{1}{2}\%$ CO_2 (representing the 720 lb. of carbon necessary for the actual reduction). These figures are for equilibrium reactions, and the excess carbon as CO must be even greater in a working furnace in order to have an appreciable rate of reduction.

Mathesius has worked out a heat balance from the operations of large 1915 furnaces making low silicon pig iron and finds that of the 12,850,000 B.t.u. needed per ton of pig iron, 10,800,000 is from the coke and 2,050,000 is brought in by the hot blast. How does this compare with the ideal?

Our figures have been for a reduction temperature of 1500° F. As the temperature goes up the conditions are less favorable because of a change in the equilibrium ratio $CO:CO_2$. At 1600° F., for instance, the theoretical requirements for reduction are about 1450 lb. of carbon, at 1700° F. 1550 lb. and at 1800° F. 1650 lb. Reduction in the blast furnace occurs over a range; 1600° F. is probably close to the average, and 1500° F. the lowest at which reduction occurs at a feasible rate.

If we consider the amount of heat produced by the combustion of carbon to that mixture of CO and CO_2 coming from the third chamber of our ideal furnace, we may figure that the amount of heat to be credited to combustion is 480 lb. C to CO_2 at 14,450 plus 863 lb. C to CO at 4453 or 10,820,000 B.t.u. This exactly balances the requirements of Mathesius' furnaces. Figuring at the very unfavorable average reduction temperature of 1800° F., the heat liberated is 12,200,000 B.t.u.

The relatively close agreement between the heat supplied on combustion of this carbon and the heat required for the furnace as a whole shows that many modern blast furnaces are operating at a very high efficiency and that the final balance is obtained by means of blast-temperature regulation. It also indicates the high degree to which the management and operation of the blast furnace have been developed, for unless there is a proper selection of the charge and fuel, a proper furnace design, a proper rate of driving, a complete balance cannot be achieved by blast-temperature regulation alone.

Furthermore, since the efficiency of modern furnaces is over 90%, based on the performance of the perfect furnace, it is clear that the more complicated devices now being promoted by inventors have little, if any, chance of producing a spectacular reduction in the coke consumed per ton of iron.

HOW THE WELDON TOOL CO.
improved tool quality...reduced
rejections...lowered operating costs
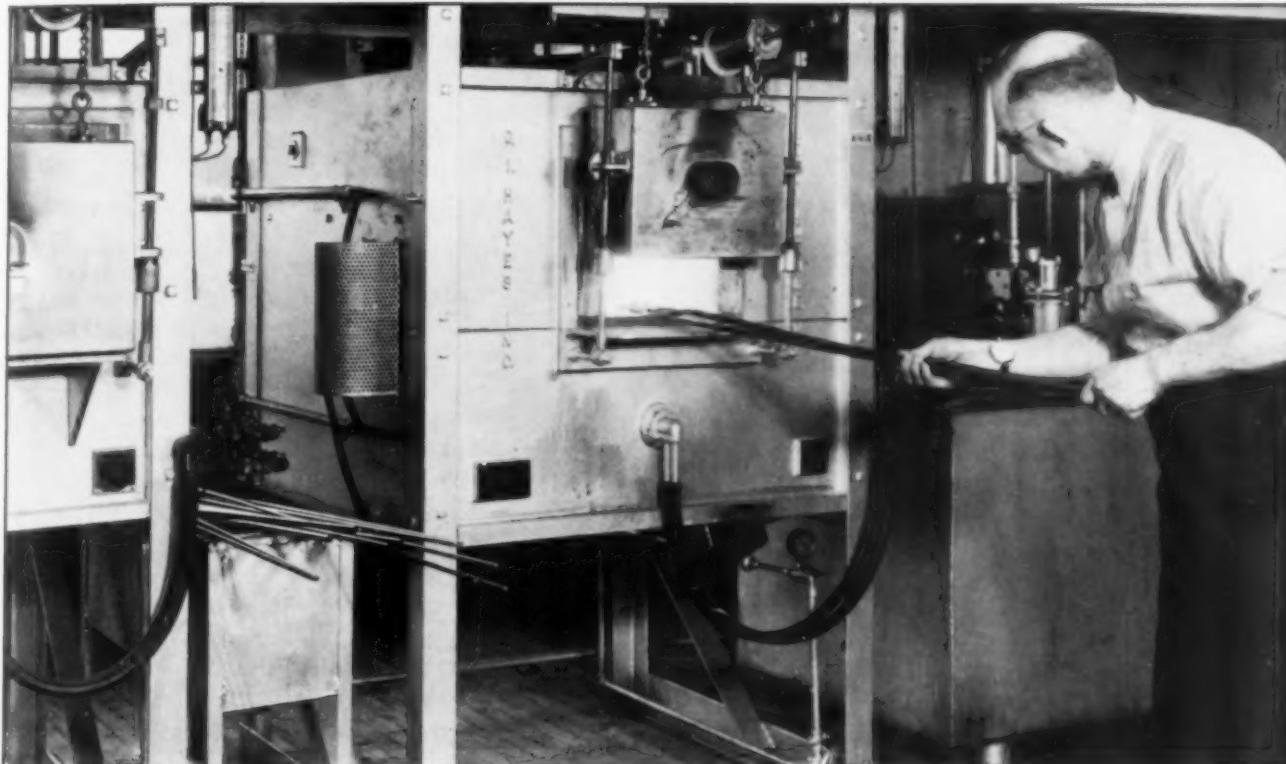
● When the Weldon Tool Co., famed manufacturers of patented double-end mills, cutters and special tools, moved into new and larger quarters they installed Hayes "Certain Curtain" Electric Furnaces equipped with Globar Brand Heating Elements. ● Mr. Elmer B. Hauser, metallurgist, speaking of these new furnaces says: "It has been possible for us to produce work that is consistently up to the highest standards because a close control over heat-treating conditions is maintained". ● "The close control of temperature and the use of controlled furnace chamber atmospheres have practically *eliminated* rejections after hardening. Soft skin, due to decarburization, has been *eliminated*. Burning and blistering of the surface and edges of fine cutting tools have been prevented and the hazards of hardening expensive tools in older types of equipment have been avoided. All of these advantages have been gained without sacrifice of economy as the maintenance costs of the furnaces are very low and the operating cost is moderate". ● Our engineers will be glad to show you how you can reduce costs and improve your product with Electric Furnaces equipped with Globar Brand Heating Elements.

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Reflections on Rupture

relative positions at a little distance in which the net inter-atomic force acting on them will still be zero. During this action, lines and planes of atoms cannot remain lines and straight — they must crumple or be otherwise distorted. This may be expected to modify profoundly the "properties" of the substance.

Fracture occurs when the external conditions are altered, if all the atoms cannot find such new positions in which they will still be subject to zero net force on the average. Fracture eventually will be initiated in the microscopic domain, and begins from some atomic instability — that is, these particular atoms cannot find new positions nearby where the inter-atomic forces are in equilibrium. Fracture is almost always initiated at some imperfection in the structure, either internal or on the surface.

Imagine now a system of forces to act so that the original ("normal") distance between atomic centers decreases; the body is so much compressed from all directions that the inter-atomic forces are on the average repulsive; rupture cannot spread from a microscopic gap between two neighboring atoms because the widening of a fissure means a compressing nearer together of the abutting atoms and so an increase of atomic potential energy.

However this gives an inkling of what happens in the experiments on limestone and powdered metal compacts. During loading (of the limestone, particularly) stress and deformation are homogeneously distributed throughout the mass. The component of stress across the plane perpendicular to the axis of compression must certainly be constant throughout the mass and equal to the compressive force acting across the ends. This stress is always compressive, except at the moment of release, when it becomes zero. At no time can there be a tensile stress in any direction.

However, during release of compressive load and hydrostatic pressure there is an extension of the body, reckoned from the configuration it had reached during plastic flow under maximum load, and this extension is greatest along the axis of compression. As long as the pressure remains high, this extension takes place stably, because the atoms are still in sufficiently close contact in all directions. But when the pressure has been reduced far enough, the corresponding extensions create unstable conditions and the body ruptures across the planes on which the extension is greatest.

This example prepares us to expect other examples of rupture on release of a state of stress which has been preponderantly compressive, but in which there have been sufficiently large differences between components of the stress to produce permanent deformation.

A magnet steel made in the open-hearth

An example of Bethlehem service to users of special steels

IT MAY sound like heresy to some, but Bethlehem makes magnet steel in the open-hearth furnace, as well as by more expensive processes. We have done so for years and have perfected methods such that the lower-cost open-hearth steel fully meets the requirements for many purposes.

The foremost consideration is that open-hearth magnet steel offers a big advantage in cost. Less tangible, but still very important to many users of magnet steel, is the uniformity. Being produced in large furnaces, 70 to 80 tons of finished bar stock are obtained from a single heat.

Whatever kind of special steel you may use, the chances are that Bethlehem can offer you something worth considering, either in service qualities, processing properties or cost.

In the Bethlehem organization all metallurgical problems are handled in a central metallurgical division. This provides for applying all of the experience obtained in contacting all industries to the task of making the best steel for any particular purpose. A unique system of control provides the means for consistently meeting highly specialized requirements.

BETHLEHEM STEEL COMPANY

BETHLEHEM STEEL

Notes about contributors

Waldemar Naujoks was born in Milwaukee, the son of the proprietor of a small tool shop specializing in hand-forged cutting tools. As a boy he picked up the rudiments of hand forging in after-school periods, and in 1912 left high school to enter the tool shop as an apprentice. In 1917, his apprenticeship finished, he joined the Navy and served for two years as forging instructor in the Charleston Navy Yard. Hankering for more schooling, he entered University of Wisconsin in 1920. Six years later (two years were spent as a high school machine shop instructor) he emerged with a B.S. degree in mechanical engineering. The degree of M.E. came later, in 1933. "Wally" Naujoks has been with Steel Improvement and Forge Co. for the past ten years, since 1933 as chief engineer. He has recently completed the manuscript of a "Forging Handbook" soon to be published by the ⊕, and presented a series of lectures on forging practice before the Cleveland Chapter last spring. The article on page 247 is slightly condensed from his Western Metal Congress paper given last March.

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Subject chosen by **Charles H. Herty Jr.** for his Doctor of Science thesis (M.I.T. 1924) was "Interaction Between Gas, Slag, and Metal in the Basic Openhearth Process." Work in this field has since continued until now Dr. Herty's name is one of the first that comes to the metallurgical mind in connection with the physical chemistry of steel making. For two years he was research associate in the Buffalo Station of the Massachusetts Institute of Technology School of Engineering Practice, stationed at the Lackawanna plant of the Bethlehem

Steel Co., but his most important work began in 1926 when he joined the staff of the U. S. Bureau of Mines and was assigned to the Pittsburgh studies into the physical chemistry of steel manufacture. This work was finished in 1934 and he has since been with Bethlehem Steel Co. as research engineer in the development and research department.

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At the risk of "having his hide tacked to the barn door and in the hope of at least arousing some interesting counter-attacks at the Detroit convention," **Edward G. Mahin** sent in a vivacious contribution to the current discussion on nomenclature of microconstituents in steel. He likes his original title, simply "Pearlite," but anyone can see that this does not fit into the typographical style selected by this issue! His claim to authority behind the opinions expressed on page 218 rests firmly on his position as head of the department of metallurgy at Notre Dame University. Mahin got his start at Purdue — a B.S. in 1901 and M.S. in 1903. Here also he went through the various teaching grades, instructor, associate professor and professor, broken only by a leave of absence from 1906 to 1908 while he tacked on a Ph.D. at Johns Hopkins. He has been in charge of the Department of Metallurgy at the University of Notre Dame since 1925.

⊕   ⊕   ⊕

A little over ten years ago, just out of University of Maryland with an electrical enginering degree, **J. H. Loux** became associated with the industrial furnace industry. For the first seven years he worked out electrical engineering details of

Charles H. Herty Jr.   Waldemar Naujoks   Walter F. Hirsch   J. H. Loux

furnaces and furnace controls. Included was a certain amount of road work and erection supervision. In 1935 he came with Salem Engineering Co. as an electrical engineer. His time there has been divided between engineering problems on equipment under construction and on proposed new designs and estimates. One such large piece of equipment recently completed is the furnace for treating aluminum alloys described on page 237.

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Extensive and up-to-date laboratories in the Endicott plant of International Business Machines Corp. were installed and organized by L. C. Conradi, who came to I.B.M. as metallurgist in 1931 and who has been technical research director since 1937. After obtaining his Bachelor of Science degree at the University of Michigan in 1914 Conradi acquired a thorough knowledge of technical research functions through assignments as chemist, assistant planning engineer, chief chemist and metallurgist in the steel, automotive, aircraft, machine tool and office accounting machine industries. That he also has the knack of explaining technical matters in easily understood language is shown by his leading article in this issue on high frequency induction hardening of small steel parts.

❋ ❋ ❋

A recent addition to the family of abrasion resistant alloys has been developed during the past five years by Walter F. Hirsch (who tells about it on page 230) at the Industrial Research Laboratories in Los Angeles. Mr. Hirsch was born in Columbus, Ohio, where he attended Ohio State University, spent several years as chemist at Buckeye Steel Castings Co., served for five years as chemist and metallurgist at Bonney-Floyd Co., and then worked for three years for Prof. D. J. Demorest of O.S.U. on private consultation projects. Six years ago he pulled up stakes and went to California, served one year as metallurgist for Warman Steel Castings Co., and then joined Industrial Research Laboratories.

L. C. Conradi   Edward G. Mahin

Nickel-Boron Iron

(Cont. from page 232)   is uniform throughout its entire depth; this is extremely important in parts where considerable wear and several reconditionings can take place before replacement is necessary.

Due to its low melting point, in combination with its other unusual properties and its extreme resistance to abrasion, we believe that this nickel-boron cast iron approaches an ideal material for lining or internally coating tubular products. In fact, it is believed that this is the only metal having such extreme hardness and abrasion resistant qualities that can be applied to the internal areas of cylindrical bodies of steel or iron in an economical manner and on a production basis. Cost of alloy and cost of application is moderate in comparison with others containing high percentages of tungsten, chromium, cobalt and molybdenum. These also are usually of high melting point, above that of the tubing or steel forgings to which such applications might be attempted. It is true that the higher melting point alloys may be applied by welding processes but it is also readily seen that this plan would be extremely limited as to areas of any great dimensions, either in circumference or length. In addition thereto, the irregular surfaces of welded-on overlays would necessitate an extended grinding operation to reduce to smooth finished surfaces and tolerances.

Two micrographs on page 232 show the structure of Xaloy and its bond with the supporting steel body. Note how the austenite grains of the alloy have grown from the steel base, forming an interlocking bond. There is also a diffusion of carbon into the steel, and this minimizes the effect of too sudden a transition from one metal to another so dissimilar.

Products made as described above were first introduced to the oil industry in the form of oil well pump barrels, plungers, and slush pump liners. Their performance there was so outstanding that the use has rapidly spread to other industries. Among the many products now produced are the following: Cylinder sleeves, machine tool bushings, pump shaft sleeves, dies for drawing and stamping, gages, rolls of special design. In these commercial uses in many fields of industry, Xaloy parts consistently show an average of many times the life of competitive products.